AD 275 990

USNRDL-467
8 January 1962

RADIOLOGICAL PROTECTIVE CONSTRUCTION

Principles for the Protection of Facilities and Their Inhabitants Against Fallout

by
W. L. Owen

U.S. Naval Radiological Defense Laboratory
San Francisco 24, California

ABSTRACT

In the event of a nuclear attack, the presence of radioactive fallout could overshadow the more immediate weapon effects. Because of its far-reaching and long-lived characteristics, fallout from a single megaton-range detonation could make thousands of square miles inaccessible for extended periods of time. The resultant loss of the use of affected but unprotected installations together with their personnel will be, in many cases, militarily unacceptable. Thus, a means is needed for saving those important manned facilities which escape the damaging effects of blast and heat but are caught within the fallout pattern.

A modified form of protective construction is offered as a defense against fallout and its effects. To derive the greatest protective benefits, this concept must be included as an integral part of a radiological defense system. By itself, radiologically protective construction is implemented by satisfying one or more of the following objectives:

1. Improving the inherent shelter effectiveness of structures
2. Minimizing the deposition and retention of fallout
3. Facilitating the removal of fallout.

To this end, a number of protective principles are presented which can be either incorporated into the design of new buildings or applied to existing buildings.

Paragraph		Page

SECTION V - APPLICATION OF PROTECTIVE PRINCIPLES IN THE DESIGN OF NEW BUILDINGS

SECTION VI. APPLICATION OF PROTECTIVE PRINCIPLES TO EXISTING BUILDINGS

LIST OF FIGURES

Figure		Page

LIST OF TABLES

RADIOLOGICAL PROTECTIVE CONSTRUCTION

TABLE OF CONTENTS

TECHNICAL DEVELOPMENTS BRANCH
P.D. LaRiviere, Head

CHEMICAL TECHNOLOGY DIVISION
L.H. Gevantman, Head

ADMINISTRATIVE INFORMATION

This document is the product of a project sponsored by the U.S. Navy. The project is described in this Laboratory's USNRDL Technical Program for Fiscal Years [illegible] and [illegible], Revision [illegible] of November [illegible], where it is designated Program B-2, Problem [illegible].

ACKNOWLEDGMENT

The author is greatly indebted to Messrs. M.B. Hawkins and H.B. Curtis, [illegible] members of the U.S. Naval Radiological Defense Laboratory, who created [illegible] the philosophy and the basic format. Mr. Hawkins was one of the first to recognize the importance of radiological statistics [illegible] and to effectively propose its investigation of the project. Mr. Curtis created the mathematical [illegible] and, with Mr. Hawkins, wrote the expanded outline first approved by the sponsor of the project.

Eugene P. Cooper
Dr. E.P. Cooper
Scientific Director

E.B. Roth
Captain E.B. Roth, USN
Commanding Officer and Director

RADIOLOGICAL PROTECTIVE CONSTRUCTION

SECTION I - PROTECTIVE CONSTRUCTION AND RADIOLOGICAL DEFENSE

1-01. IMPORTANCE OF RADIOLOGICAL DEFENSE AND ROLE OF PROTECTIVE CONSTRUCTION. The development of high-yield nuclear weapons and the capability to deliver them means far more than an increase in the radius of destruction due to blast, shock and heat. An explosion on or near the earth's surface creates an insidious anti-personnel hazard in the form of "radioactive contaminant" or "fallout". Over-exposure to the persistent radiation accompanying fallout can cause incapacitating illness and death. The hazard may continue for days or weeks within a fallout area many times greater than the zone of immediate physical damage.

In the absence of an adequate radiological (fallout) defense system, a well executed contaminating attack could, in addition to causing numerous personnel casualties, deny access to thousands of square miles and prevent the remanning of important installations for protracted periods of time. Thus fallout not only poses a threat to survival, but it endangers unprotected facilities that may be vital to the nation's military capability. Consequently some form of protective construction must be employed as a first line of defense in an effective radiological defense system.

In military language the term "protective construction" means the incorporation of blast resistant-features in structures. This interpretation has been the basic approach in the passive defense against nuclear attack, founded on the belief that blast resistance insures protection against the other weapon effects. Unfortunately, such an approach does not take into account the full implications of contaminating attacks and the need for an effective radiological defense.

First, a blast-resistant concept in protective construction neglects the long-term aspects of the fallout hazard. Although occupants of a strengthened facility survive the immediate effects of a nuclear explosion, they may become virtually imprisoned by the radioactive fallout. In cases of heavy concentrations of fallout, waiting for natural decay or for rescue could result in stay periods of intolerable duration. Unless protective construction includes the means for protecting against the radiation and initiating the radiological recovery of an installation, resident personnel cannot remove the cause of their imprisonment and effectively resume the basic mission.

Second, the blast-resistant approach fails to take into account the magnitude of the fallout problem with respect to the relative sizes of the areas affected by the separate weapon effects. The extent of such effects due to a 1-megaton surface detonation are given in table 1-I. The entries

Table 1-I. Approximate Size of Areas Affected by a 1-Megaton Surface Detonation

Effect	Quantity	Approx. Extent (mi.) Radius or 1/2 Width	Approx. Extent (mi.) Downwind Range	Area Affected ($mi.^2$)	Area Affected Relative* (%)
Blast					
Virtual destruction of most buildings		1	-	3	0.1
Severe to moderate damage to wood or light steel frame buildings		4	-	50	2
Moderate to slight damage to wood or light steel frame buildings		6	-	113	4.5
Slight damage to building components (windows broken)		15	-	700	28
Thermal Energy**					
Fires and 2nd degree skin burns	7 cal/cm^2	6	-	113	4.5
1st degree skin burns	3 cal/cm^2	9.5	-	284	11
Nuclear Radiation					
Initial gamma and neutron (fatal) dose	700 rem.***	1.5	-	7	0.3
Fallout dose to 24 hr. after weapon detonation (r. = roentgens)	4000 r.	1	3	5	0.2
	1000 r.	3	70	60	2.5
	500 r.	5	160	700	28
	100 r.	10	190	2500	100

* Values derived from ratio of gross area to 2500-$mi.^2$ area encompassed by 100-r. contour.

** Transmission of thermal energy is highly dependent upon atmospheric conditions. The ranges given tend to represent average values.

*** See subsection d, section 3-01.

clearly show that the area contaminated by fallout is far greater than that of any other effect. For example, at 24 hours after burst the area contained within a typical 100[1] roentgen dose contour is estimated to be 2500 square miles. By comparison the appreciable damage due to blast and thermal effects cover little more than 100 square miles, or 4.5 percent of the significant 100-roentgen fallout pattern. Severe blast damage encompasses only about 2 percent of this same area and lies within the region of very heavy fallout.

In the case of high-yield explosions the fallout hazard is further increased by the presence of an extensive, high dose region. Although situated many miles from ground zero, the radiation intensities in this particular region rival those normally expected in the zone of immediate damage. This, together with the above comparisons from table 1-I, serves to illustrate the magnitude of the radiological problem relative to that created by blast and heat.

From the foregoing it is evident that fallout protection alone could reduce the "gross" effect of a 1-megaton weapon 95 percent and therefore deserves first consideration in protective construction. Admittedly, one cannot predict the degree of protection required at a specific location prior to an attack. However, from a consideration of the relative sizes of the affected areas involved, adequate preparation against fallout can allow a significant number of critical installations to effect a satisfactory recovery. Because fallout protection can be implemented by proper planting of present day construction, it is immediately and economically feasible.

For the purposes of this handbook the term "protective construction" will refer only to the resistance of structures to fallout and its effects. Any implication of resistance to blast and heat, which is ordinarily associated with protective construction, will be the exception rather than the rule. This is not to be considered a handbook on blast or thermal protection.

1-02. ADVANTAGES OF RADIOLOGICAL PROTECTIVE CONSTRUCTION. The concept of protective construction offers two advantages not generally possible with other radiological defense measures. First, it is fully carried out before attack comes, requiring no further effort. Second, besides providing direct protection to persons in buildings, it contributes to the effectiveness of a post-attack recovery effort. Specifically, a realistic program of fallout protection for structures may, in the event of a contaminating attack, greatly lessen personnel casualties and loss of critical installations by:

1. Shielding persons from penetrating (gamma) radiations.
2. Facilitating the riddance of fallout from structural exteriors.
3. Partially reducing physical damage to structures and their contents resulting from blast and thermal effects.

1. This is an arbituary value used for only an example and is not to be construed as a limiting value for 24 hours.

The second contribution would speed recovery operations and hasten the eventual resumption of facilities' functions. In addition, a shortened recovery period means less radiation dosage to recovery teams.

1-03. SCOPE AND PURPOSE OF HANDBOOK. The handbook is intended as a tool for engineers and architects in the selection of materials, methods of construction, and maintenance procedures in the design and upkeep of land-based facilities. It is limited primarily to radiological defense considerations, because the problem of contamination by fallout overshadows that created by the blast and thermal effects of nuclear explosions.

Although the handbook is not an operational guide, recovery procedures are included to help the designer or engineer visualize the required utilities and anticipate problems likely to be encountered during the recovery phase.

The handbook has two purposes:

1. To present information which will provide a basis for: (a) selecting the kind of radiological protection required and (b) evaluating the effectiveness of selected protective measures.
2. To provide data related to the actual design and construction of protective features.

In order to serve these purposes, the handbook will:

1. Present principles of protection against all effects for both personnel and facilities, along with available technical data.
2. Show the relation of the radiological hazard of nuclear weapon detonations to the other effects.
3. Provide relative cost and effectiveness data for protective measures through which the principles are to be applied.
4. Give procedures for radiological recovery along with associated effectiveness and effort data.

SECTION II - RELATIVE IMPORTANCE OF NUCLEAR EXPLOSION EFFECTS

2-01. GENERAL EFFECTS OF NUCLEAR EXPLOSIONS. The unleashing of a vast amount of energy in a very small space, by a nuclear detonation, results in several damage-producing effects. One of these, blast, is caused by the violent pressure wave which travels with supersonic speeds at early times and then continues at sonic speeds outward over the target area. Near the explosion center, air blast generally causes physical damage and personnel injury and death. Similar damage is created by shock waves in ground (or water) as a result of surface or subsurface bursts.

Another effect of the instantaneous release of energy is the radiation of heat and light from the fireball produced by the explosion. The heat flash is capable of igniting fine tinder-like materials, charring thicker ones, and severely blistering the skin of exposed personnel. If the target is a densely built-up urban industrial area, any resulting small fires can eventually combine into a gigantic mass fire. Such a mass fire, in the case of an air burst, would be the major cause of damage and casualties.

At the same time that the thermal flash is occurring, large quantities of nuclear radiation are emitted from the fireball, consisting of gamma rays and neutrons. These, called "initial" nuclear radiations, are effective during the minute or less that the fireball is near the surface. In general, initial radiation is a hazard to personnel only in the region where severe thermal and blast effects are also present. However, some people who are sheltered against the other effects of the attack may still become casualties from initial radiation.

Air blast, shock, and thermal and initial radiation effects have certain features in common. Their pattern about the point of detonation is circular, and their power diminishes rapidly with distance from this point. Also, the duration of these effects is extremely short for all weapon yields. Thus, without prior warning there is little or no time for exposed personnel to find protection from these immediate effects.

While the immediate effects occur, the intensely hot fireball rises rapidly into the sky. When it cools, it forms the mushroom cloud that is characteristic of a nuclear detonation. This cloud contains the fission products of the detonation and is therefore highly radioactive. If mixed with target and crater material, these radioactive products fall back to the ground not only in the vicinity of the detonation, but also in sizable areas downwind. The resultant penetrating radiations can cause numerous casualties. Under these conditions, radioactive fallout often can be the most significant personnel hazard resulting from nuclear attack.

The radiological event (transport and deposition of fallout) and its consequences, unlike the immediate effects, are lengthy and their duration

is not easily predictable. At a given location it may take from half an hour to a day or more for the deposition of fallout. Because the descending fallout is subjected to the varied velocities of winds aloft, the affected area is neither circular nor symmetrical with respect to the explosion center but extends in an irregular pattern downwind.

2-02. TYPES OF NUCLEAR EXPLOSIONS. The relative importance of the various effects of nuclear attack depends mainly upon the location of the detonation relative to the earth's surface. Therefore it is convenient to divide nuclear attacks into three basic types: air, surface and subsurface. Actually there is no sharp line of demarcation between the types of attack. The air burst gradually takes on the characteristics of a surface burst as the height of burst is lowered.

An "air burst" is a detonation sufficiently high in the air so that the fireball never comes in contact with the surface of the ground. For a 1-megaton detonation, this means that the height of burst must be at least 3000 feet.[1] While the effects of an air burst vary with the height of burst, it can be said, in general, that an air burst maximizes the ranges of thermal radiation and low-to-moderate blast pressures, and minimizes the effects of cratering, ground shock and radioactive fallout. Therefore, an air burst is best suited for use against lightly constructed target elements or densely built-up regions vulnerable to mass fires.

A "surface burst" is a detonation at or near the earth's surface so that the fireball contacts the surface. Again the effects vary with the exact height of burst. In general, the surface burst maximizes the range of high blast pressures and initial nuclear radiation and produces radioactive fallout. The range of thermal radiation damage is reduced because of heat loss to the ground and obscuration of the fireball. The surface burst also causes important cratering and ground or water shock effects. Surface bursts can be very effective against "hard" target elements such as piers and docks, marshalling yards, runways, and shops. The attendant fallout radiation can incapacitate or kill personnel and prevent use of facilities over a large area.

A "subsurface burst" is a detonation occurring below the surface. Subsurface bursts are sometimes classified as underground and underwater bursts. Most harbors are so shallow that a burst on the bottom of a harbor will be similar to a land surface burst. The subsurface burst maximizes cratering, ground or water shock, and fallout areas of very high dose rate near the point of detonation, while minimizing thermal effects and air blast. It may be most effective in blocking routes of communication and in destroying underground installations.

Both surface and subsurface bursts result in the contamination of large areas with significant amounts of radioactive fallout. These types are called contaminating nuclear attacks and are the major concern of this handbook.

1. Reference I in bibliography.

SECTION III - DESCRIPTION OF NUCLEAR WEAPON EFFECTS

A great deal of the information presented in this chapter was extracted from reference 1, "The Effects of Nuclear Weapons". In this reference the reader will find a rather detailed and technical description of nuclear weapon effects.

3-01. NUCLEAR RADIATION. The distinguishing feature of a nuclear detonation is the fact that it is accompanied by the emission of nuclear radiation. These radiations, as distinct from thermal, consist of gamma rays, neutrons, and alpha and beta particles. Essentially all the neutrons and some of the gamma rays are emitted in the actual fission process (during the nuclear explosion). Some of the neutrons are immediately absorbed by non-fissionable nuclei, and this capture process is usually accompanied by the instantaneous emission of gamma rays. The remainder of the gamma rays and the beta particles are liberated while the fission products undergo radioactive decay. Some of the alpha particles result from the decay of uranium or plutonium that has not been consumed in the fission process, while others are formed in hydrogen fusion reactions.

a. Definitions, Sources and Properties of Nuclear Radiations. In considering a nuclear explosion, either in air or near the surface, it is convenient to divide the resultant radiations into two categories, initial and fallout. The distinction is based on the various radiation sources produced by the explosion, as shown in table 3-I. Briefly, the initial radiation[1] is that which accompanies the instantaneous fission/fusion process, and this radiation terminates with the explosion. The fallout radiation is of long duration since it is emitted by fission/fusion products. Although these radioactive particles exist in the rapidly rising cloud, their eventual descent and deposition result in the fallout hazard. For relatively shallow subsurface explosions the initial radiation loses much of its importance, since a large portion of it is absorbed by the ground. For deeper detonations the initial radiations become negligible, and only the fallout radiation need be considered.

Table 3-II identifies, by basic composition and significant properties, the four types of radiation accompanying a nuclear detonation. The table shows that, because of their low penetrating power, alpha and beta particles do not represent a source of radiation injury to properly clothed and equipped personnel [2] Therefore the more harmful radiations are the neutrons and

1. Some publications class as initial all those nuclear radiations occurring within an arbitrary time of one minute after burst.
2. Fallout materials which emit alpha and beta particles may create contact and inhalation hazards. Adequate protection may be achieved by respirators or face masks together with suitable clothing. These serve to prevent ingestion and minimize exposed skin area, when personnel work in dusty, contaminated regions. Further discussion of this problem is beyond the scope of the handbook.

Table 3-I. Occurrence of Neutrons and Gamma Rays According to Radiation Sources

Initial Radiation (Occurs During Nuclear Explosion)	Fallout Radiation* (Occurs After Explosion)
Gamma Rays	
Includes initial gamma rays produced by: 1. fission process. 2. neutron reactions. 3. excitation of air and bomb materials.	100 percent of fallout gamma rays are emitted by weapon and target debris: 1. mainly fission products (approx. 200 isotopes). 2. some unfissioned uranium and plutonium. 3. induced activity in bomb structure and target materials.
Neutrons	
Practically all neutrons appear in the first millionth of a second in the following proportions: 1. over 99 percent of fission neutrons, and 2. 100 percent of fusion neutrons.	No neutrons are present, having been completely expended with the initial radiations.

*Associated with surface and subsurface explosions only.

gamma rays. Returning to table 3-I it is obvious that, except for the first instant during the explosion, essentially all the radiations consist of gamma rays, from the decay of fission products. It is with this form of radiation that the handbook is primarily concerned, particularly those gamma rays which emanate from the radioactive fallout material.

b. Units of Radiation Measure. The dose accompanying exposure to gamma radiation can be expressed with a suitable unit of measurement. The "roentgen" normally is used since dosage so expressed is presumed to be relatable to the anticipated biological effect (or injury).

It is generally believed that nuclear radiations harm living organisms through chemical decomposition of the molecules present in animal or vegetable cells. Fundamentally, the ionization and excitation caused by nuclear

Table 3-12. Definitions and Properties of Nuclear Radiations

Type of Radiation	Source and Composition	Range in Air: Initial Radiation	Range in Air: Fallout Radiation	Power of Penetration	Personnel Hazard
Alpha (α)	Positively charged particle emitted from nuclei of uranium and plutonium atoms, consists of 2 protons and 2 neutrons. Identical to a helium nucleus.	Several yards.	1 to 3 inches.	Weak, stopped by the skin.	Internal contamination due to ingestion.
Beta (β)	Negatively charged particle emitted from nuclei of atoms comprising most fission fragments. Identical to high speed electron.	Several yards.	Several feet.	Weak, stopped by ordinary clothing.	Same as above plus skin burns due to prolonged contact of deposits on skin.
Gamma (γ)	High energy electromagnetic radiation originating in nuclei of radioactive elements and in nuclear reactions. Identical to high energy X-rays.	A few[1] miles.	Hundreds[1] of feet.	Strong, moderated by inches of dense metals or by a few feet of concrete and/or earth.	Harmful ionization of tissue due to external radiation even at long range.
Neutron (n)	Electrically neutral particle emitted during fission and fusion reaction. A basic component of all atomic nuclei except hydrogen.	A few miles.	Neutrons all spent prior to fallout phase.	Very strong, moderated by several feet of concrete and/or earth. Sensitive to moisture content.	Same as above.

1. Refers to range of gamma intensity, taking into account the relative difference in source strength.

Table 3-III. Acute Effects of Whole-Body Gamma Exposure

Dose Received in < a Week	Effect
0-150 r	No acute effects - serious long-term effects.
150-250 r	Nausea and vomiting within 24 hours; minimal incapacitation after 2 days.
250-350 r	Nausea and vomiting within 4 hours. Symptom-free period 48 hours to 2 weeks. Some deaths may occur in 2 to 4 weeks.
350-600 r	Nausea and vomiting under 2 hours. Death certain in 2 to 4 weeks. Incapacitation prolonged in possible survivors.
> 600 r	Nausea and vomiting almost immediately. Death in 1 week.

and distance from the point of detonation. For these radiations it is convenient to deal with the combined neutron and gamma ray effects. Not only do they both extend over approximately the same time interval, but the injuries they cause in human beings are similar.

Figure 3-1[1] shows the shift in the relative contribution of neutron and gamma radiations with changes in weapon yield, for biological doses of 600 and 200 roentgens-equivalent-man.[2] It is evident from these curves that for high doses and low energy yields, neutrons make a larger contribution than do gamma rays. When doses are moderate and energy yields high, the reverse is true.

In general, the neutron dose will exceed that of the gamma radiation near the explosion center. However, with increasing distance the neutron dose decreases faster, such that beyond a certain point the gamma radiation predominates. Ultimately, the neutron contribution to the total initial dose becomes comparatively insignificant.

The net result of the foregoing relationships between total initial radiation dose, yield and distance is presented in figure 3-2.[3] From the

1. Reference 1 in bibliography.
2. The biological dose in rems (roentgen-equivalent-man) due to gamma rays is numerically equal to the absorbed dose in rads and is approximately equal to the exposure dose in roentgens.
3. Reference 4 in bibliography.

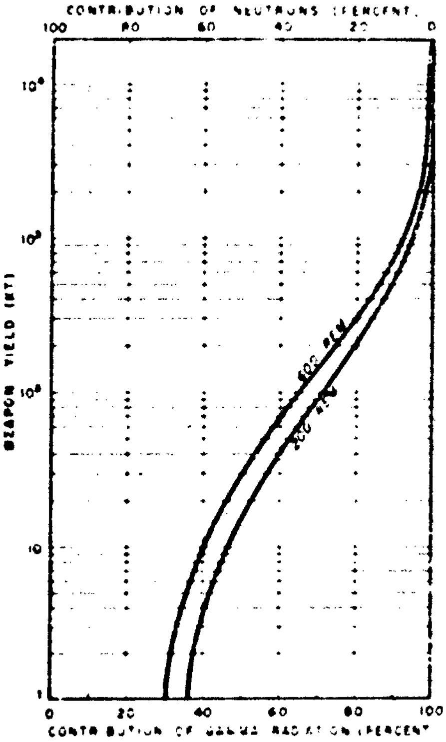

Figure 3-1. Relative Contribution of Neutron and Gamma Radiation to Total Biological Dose.

curves and the indicated range of lethal effects, it is apparent that some deaths are possible at distances of 1-1/2 to 2-1/2 miles for weapons of multi-megaton yield. However, it will be noted later (in section 3-03) that for surface detonations the range of severe blast damage will equal or even exceed the range of lethal dosage. Thus, the effects of serious initial radiations become secondary in the face of the almost complete destruction caused by the explosive forces - especially where high yields are anticipated.

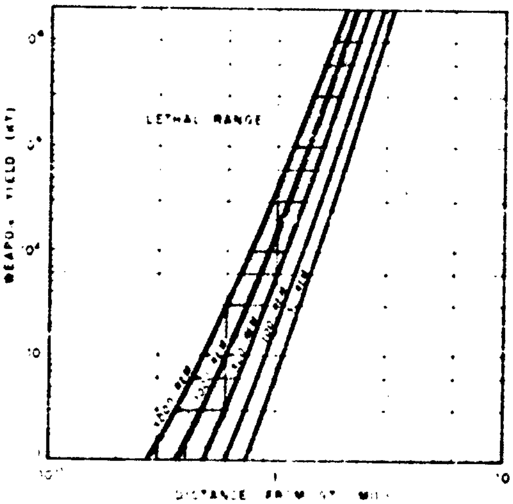

Figure 3-2. Ranges for Total Initial Radiation Dosages - Neutron Plus Gamma.

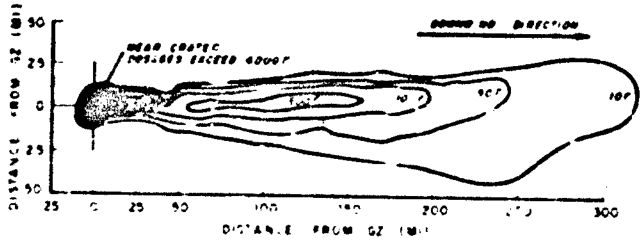

Figure 3-3. Fallout Pattern Based on Dose Accumulated After 24 Hours, for a 1-MT Surface Burst.

Following a surface or subsurface burst, a serious continuing radiation hazard exists in the form of gamma rays from the decay of fission products, etc. As noted in table 3-I these radiations have their source in the radioactively contaminated weapon debris comprised of bomb components and target material. This debris is deposited as local[1] or "close in" fallout over an extensive area whose major portion is located downwind from the explosion center. A number of hours may elapse before completion of the fallout event. The length of this fallout interval as well as the extent and shape of the fallout pattern will depend upon weapon yield, altitude of debris prior to its descent, debris particle size and wind velocities.

Figure 3-3 represents a fallout pattern in which the contours indicate the doses accumulated by 24 hours after a one-megaton surface detonation. As expected, the contours indicate the fallout dose to be greatest near ground zero (the point directly above (or below) the explosion center). However, contrary to the idealized fallout patterns still in use, the contours of figure 3-3 exhibit a separate and critical dose area of considerable dimension located some distance downwind. The secondary 500-roentgen dose contour defines this area (frequently called the downwind peak), in which it is possible to receive an injurious or even lethal dosage.

The contours in figure 3-3 should not be construed as being limiting in either extent or degree. Additional contours for still smaller doses may be plotted beyond the 10-roentgen contour, thus enlarging the fallout pattern. For times greater than 24 hours after burst these same contours would have still larger dosage values, because of the continuing radioactive decay process. Even though the radiation rate from the deposited fallout steadily diminishes with time, its effects are additive, causing a gradual increase in the accrued exposure dosage over a period of many months.

From the foregoing, it is obvious that fallout presents a significant hazard to exposed personnel over long periods of time and at great distances from the explosion, i.e., well beyond the region of immediate danger (the region encompassing blast, shock, thermal and initial radiation effects). For this reason the major portion of the handbook will deal with the slanting of construction to provide protection against fallout effects.

e. Fallout Characteristics. To gain a better understanding of the problems created by fallout, this section discusses fallout formation, distribution, composition, and its chemical, physical and radioactive properties.

1. The terms "local" and "close in" refer loosely to fallout deposited within hundreds of miles of the explosion as differentiated from "long range" fallout which travels thousands of miles or "world-wide" fallout which may circumvent the globe.

In a land surface burst, large amounts of earth, dust, and debris are taken up into the fireball in its early stages. Here they are fused or are vaporized and become intimately mixed with the fission products and other bomb residues. As a result, a tremendous number of small particles are contaminated with the radioactive products of the explosion.

The larger particles (those greater than 750 microns in diameter), which include material thrown out of the crater, are probably not carried up all the way into the mushroom cloud, but descend from stem altitudes. Some of this material falls in a roughly circular pattern around ground zero, and the remainder falls downwind from ground zero. Most of these particles descent within an hour or so after burst.

The smaller particles (those between 75 and 750 microns in diameter) present in the column are lifted upward to a height of several miles and carried out some distance by the mushroom cloud before they begin to descend. The time taken to reach the earth and the horizontal distance traveled will depend upon the height reached before their descent, the size of the particles, and the wind pattern in the upper atmosphere. Many hours may elapse before the bulk of the larger particles(in this size range) reaches the earth. This material comprises the local and, hence, militarily significant fallout region generally situated downwind from the explosion and covering thousands of square miles.

The smallest particles, like those formed in an air burst, fall so slowly from the stratosphere altitudes that they remain suspended for long periods and travel thousands of miles before descending to earth as "long rang" fallout. A certain fraction of these fine particles are essentially stored in the stratosphere and sift down gradually for years as "world-wide" fallout. The immediate military significance of the world-wide fallout is unimportant, hence it will not be further discussed in this handbook.

Returning to the local fallout problem, gross fallout material consists of soil whose principal source is pulverized target and crater materials. Thus the environment of the explosion will, for all practical purposes, determine the amount of fallout material as well as the size and form of the individual particles.

Table 3-IV indicates that the detonation environment has a marked effect on still other important fallout characteristics. Thus far, all discussion has referred to fallout particles originating with nuclear explosions on land. However, it is possible to generate two other basic types of fallout. Detonations in deep water may result in a contaminant whose basic constituent is sea salt. In humid climates this same material may arrive in solution as a fine mist, which is classified as wet fallout. A shallow water burst, as in a harbor, may create a type of fallout which would be nearly dry by the time of deposition.

Table 3-IV. Chemical and Physical Characteristics of Local Fallout From a Large-Yield Surface Detonation in a Temperate Climate

	Detonation Environment		
	Deep Seawater	Land	Shallow water
Primary constituents:	Seawater salts and hygroscopic water, plus possibly Al and Fe from bomb or target ships.	Pulverized plus fused and sintered earth.	Pulverized, fused and sintered bottom material, plus lesser amounts of deep seawater constituents.
State of fission products:	In solution; fused in fine particles, ranging down to colloidal sizes.	Fused in or attached to soil particles.	Fused in or adsorbed on soil particles.
Estimated amount on surface at significant radiation levels (g/ft^2):	0.1 - 10*	3 - 300	1 - 300**
Surfaces contaminated:	Both horizontal and vertical.	Principally horizontal.	Both horizontal and possibly vertical.
Degree of decontaminability:	Very tenacious.	Very loose.	Intermediate between tenacious and loose.

* Dry salt weight; negligible dry weight if source is deep fresh water (> 200 ft).
**Depends on water depth.

Because of the strong attraction between radioactive ions and surfaces by virtue of chemical reaction, absorption and adsorption processes, or mechanical adhesion, wet fallout is more difficult to decontaminate than either of the other two types. Fortunately, the more readily removable dry contaminant is the most likely form to be encountered by most land-based installations. Wet contaminant is a special problem to surface ships and shore bases but will not be further treated in this handbook.

The point was made earlier that the fallout exposure dose continues to build up indefinitely even though the dose rate decreases with the radioactive decay of the fission products in the fallout. Figure 3-4 gives a somewhat idealized curve depicting the growth and decline in the fallout dose rate at a given position downwind from ground zero. In this particular instance, the fallout is shown to arrive at about 5 hours, and the dose rate to reach a peak 10 hours after burst. Because the radiation intensity is proportional to the amount of radioactive material present, the dose rate increases as the fallout builds up. Upon termination of fallout (after 10 hours) the decay process alone is evident and the dose rate promptly starts to diminish.

The total dose accrued at any given time is equal to the area under the dose rate curve extending from the start of fallout to the time of interest. Thus, the fallout dose will always be an increasing function of time as shown by the second curve in figure 3-4, rising steeply during fallout and gradually leveling off after fallout. It becomes asymptotic to the horizontal line labeled $t - \infty$, which for this particular graph has a value of about 35 roentgens. This limiting value is called the "infinity dose", which, for all practical purposes, is reached in about 1-1/2 to 2 years from time of burst.

It is most difficult to predict the shape of the dose rate curve during the time of fallout, even if the irregularities usually caused by weather changes are ignored. However, results from weapons' tests have shown, that after fallout cessation, portions of the actual dose rate curve can be very nearly approximated by straight lines on a logarithmic plot such as figure 3-4. For such instances it is possible to make rough estimates of dose rates at later times. The accumulated dosage may then be obtained by summing the area under the dose rate curve (either by analytical or graphical integration).

In the foregoing discussion of dose, the gamma rays, because of their long range and high penetrating power, are much more significant than beta particles, provided the radioactive material does not make contact with the skin or enter the body. Consequently, the beta radiation can be neglected in estimating the variation with time of the dose rate from the fallout radiation. If the fraction of fission product disintegrations accompanied by gamma ray emission and the energy of the gamma ray photons remained essentially constant with time, the dose rate (in roentgens per

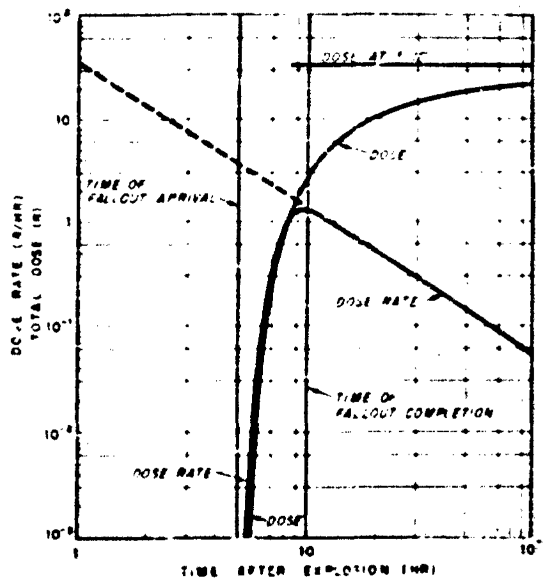

Figure 3-4. Relationship of Dose Rate to Total Dose With Respect to Time.

Figure 3-5. Variation of Overpressure Along an Arbitrary Time Scale - at a Fixed Distance From Ground Zero.

hour) would be directly related to the rate of emission of gamma rays. This is not the case, since the gamma rays in the early stages of fission product decay have, on the average, higher energies than in the later stages. However, for the periods of practical interest commencing a few hours after the explosion, the mean energy of the gamma ray photons may be taken as being about 0.7 million electron volts through the first day and between 0.6 and 0.5 million electron volts thereafter through the first year.[1]

3-02. AIR BLAST AND GROUND SHOCK. One of the major causes of physical damage accompanying a nuclear event is the tremendous force exerted by the blast wave in air. This force or blast effect is generally studied in terms of changes noted in air pressure. For instance a sudden increase of about 1/2 pound per square inch in the atmospheric pressure would probably cause some blast damage to nearly all conventional structures. The distance to which such an over-pressure extends will depend, to a large degree, upon weapon yield and burst height. Before reviewing its effects, however, it is necessary to discuss the propagation and behavior of such a pressure wave.

a. Characteristics of the Blast Wave. As mentioned in section 2, the rapid expansion of intensely hot gases in the fireball causes an air expansion which results in the formation of a blast wave that moves radially outward with speeds generally greater than that of sound. This wave's outstanding characteristic is that the pressure is highest at the moving front and falls off behind the front. As the blast wave travels through the air the overpressure at the front gradually lessens, as does the pressure behind it.

The variation of pressure with time, as observed at some fixed location (far enough from ground zero that a negative phase has developed) during the first few seconds following a detonation, is shown in figure 3-5.[2] Numeral 1 is the time of explosion. The pressure at a particular location remains ambient until the shock front arrives, at point 2. This arrival is accompanied by a strong (transient) wind which, together with the overpressure, decreases rapidly with time. The overpressure coincides with ambient at point 3. The interval from 2 to 3 represents the positive phase, which for a 1-megaton burst lasts from two to four seconds. Most of the blast destruction occurs during this phase. The pressure continues to drop below that of the surrounding atmosphere, creating the negative (or suction) phase indicated by the time interval from 3 to 5. During this phase the wind changes direction and blows toward ground zero. Since the maximum negative pressure is always smaller than the peak overpressure at the shock front, any damage produced by the negative phase is generally minor. When the negative phase passes, the pressure again returns to ambient at point 5 and stabilizes.

1. Reference 3 in bibliography.
2. Reference 1 in bibliography.

Although the destructive effects of the blast wave have usually been related to values of the peak overpressure, another quantity is equally important, the "dynamic pressure." The dynamic pressure is a function of the wind velocity and the density of the air behind the shock front. It is usually smaller than the overpressure, although for very strong shocks the dynamic pressure is greater. Like the peak shock overpressure, the peak dynamic pressure decreases with increasing distance from the explosion center, although at a different rate.

Some indication of the corresponding values of peak overpressure, peak dynamic pressure, and maximum blast wind velocities in air at sea level are given in table 3-V.[1] It should be understood that the arrival, duration, and passing of the shock front occurs within seconds. Furthermore, the times are a function of weapon yield and distance from the explosion center.

Table 3-V. Overpressure, Dynamic Pressure, and Wind Velocity in Air at Sea Level

Peak Overpressure (psi)	Peak Dynamic Pressure (psi)	Maximum Wind Velocity (mi/hr)
72	75	1170
69	69	11[illegible]
50	40	940
30	16	670
20	8	510
10	2	290
5	0.7	160
2	0.1	70
0	~ 0	~ 0

Extent of blast damage, however, depends upon burst height as well as explosion energy. The curves in figure 3-6[2] indicate this, comparing for air and surface bursts the variation in peak values of overpressure and dynamic pressure as a function of distance for a one-megaton detonation. It is clear from the curves that, at lower pressure values, both the overpressure and dynamic pressure extend farther for an air burst than for a surface burst. Conversely, a surface detonation will create far greater pressure (and damage) in close near ground zero than will an air burst. These relationships hold regardless of the weapon yield.

1. Reference 1 in bibliography.
2. Reference 4 in bibliography.

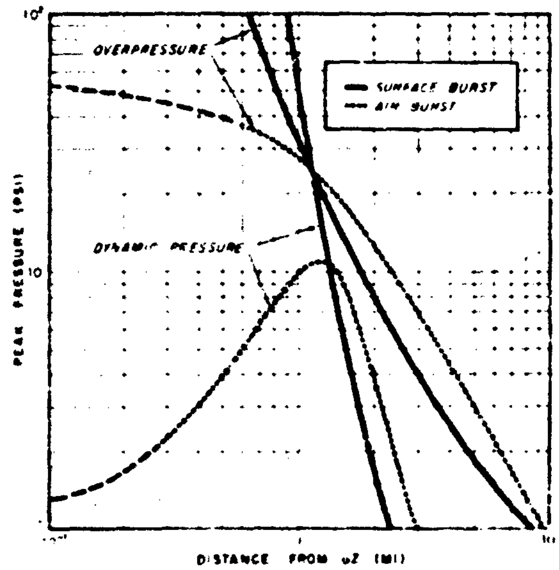

Figure 3-6. Ranges of Peak Overpressure and Peak Dynamic Pressure at the Surface for Typical 1-MT Air and Surface Bursts.

b. Interaction of Blast Wave With Structures. As implied in the previous section, the blast wave from a nuclear explosion can inflict damage of varying degree to exposed structures. The response of a building to the forces comprising the blast loading may result in a permanent distortion; e. g., deflected frames, collapsed roofs, dished in walls, shattered panels, and broken windows. Besides the more direct form, indirect damage may also arise from large movable objects thrown up against buildings. Furthermore, glass, wood splinters, bricks, pieces of masonry and other material loosened and hurled through the air by the blast wave form destructive missiles. When the front of an air pressure wave strikes the face of a building, reflection occurs. As a result, the overpressure builds up rapidly to at least twice, and generally several times, that in the incident shock front, depending upon the attitude of the wave front with respect to the building and the magnitude of the overpressure. While the front moves forward the pressure wave bends or "diffracts" around the structure, engulfing it and eventually exerting approximately the same

pressure on all the walls and roof, and the overpressure on the building face drops quickly to its original value.

Before the blast wave completely surrounds the structure, a considerable pressure differential occurs between the front and back faces. This produces a lateral (or translational) force, tending to cause the structure to move bodily in the same direction as the blast wave. This force is known as the "diffraction loading" because it operates while the blast wave is being diffracted around the structure. The extent and nature of the actual motion will depend upon the size, shape, and weight of the structure, and how firmly it is attached to the ground.

When the blast wave envelops the building, the pressure differential disappears since the pressure on all sides has essentially equalized. However, since these external pressures remain greater than the ambient pressure until the positive phase of the shock wave passes, the diffraction loading is replaced by an inwardly directed compression loading. In a structure with no openings, this ceases only when the overpressure drops to zero.

The damage caused during the diffraction stage is determined by the magnitude and duration of the overpressure loading. If a structure has no openings, loading lasts for very nearly the time in which the shock front moves from front to back of the building. For thin structures, such as telegraph or utility poles and smoke stacks, the diffraction period is so short that the corresponding loading is negligible. In general, a diffraction-sensitive structure (one primarily sensitive to peak-overpressures) has moderately small window and door areas and fairly strong exterior walls. This category includes multistoried, reinforced-concrete buildings, large wall-bearing structures such as apartment houses, and wood frame dwellings.

If a building subjected to blast effects has openings or opening covers that fail (windows, doors, curtain walls, etc.), the inside and outside pressure may quickly equalize. This tends to reduce the diffraction loading and eliminate the squeezing action that usually follows. The response of the structure is then mainly due to the dynamic pressures characterized by the strong (transient) winds which accompany the positive phase of the blast wave. The resultant translational force is called the "drag loading".

The drag loading is influenced by certain features (primarily the shape and size) of a structure, but is largely dependent upon the peak value of the dynamic pressure and its duration at a given location. Steel (or reinforced concrete) frame buildings with light walls made of asbestos cement, aluminum, or corrugated steel, quickly become drag-sensitive because the walls fail at low overpressures This failure, accompanied by pressure equalization, occurs very soon after the blast wave strikes the structure, so that the frame is subject to a relatively small diffraction loading. The distortion, or other damage, subsequently experienced by the

frame, as well as by narrow elements of the structure, e. g., columns, beams, and trusses, is then caused by the drag loading.

Although the dynamic pressure is contributing, the response of drag-sensitive structures and their components depends largely on the duration of the drag loading. Consequently, for a given peak pressure, damage to drag-sensitive buildings increases with weapon yield because the positive phase duration increases. This accounts for the fact that blast waves from nuclear weapons cause more destruction than might be expected from peak overpressures alone.

The following tables and graphs provide a rough idea of the blast pressure effects on various structures and certain of their elements. Table 3-VI[1] is restricted to diffraction-sensitive structural elements

Table 3-VI. Conditions of Failure of Diffraction-Sensitive Elements

Structural Element	Failure	Approximate Incident Blast Overpressure (psi)
Glass windows, large and small.	Usually shattering, occasional frame failure.	0.5 - 1
Corrugated asbestos siding	Shattering	1 - 2
Brick wall panel, 8 or 12 in. thick (not reinforced).	Shearing and flexure failures.	7 - 8
Wood siding panels, standard house construction.	Usually failure occurs at the main connections, allowing a whole panel to be blown in.	1 - 2
Concrete or cinder-block wall panels, 8 or 12 in. thick (not reinforced).	Shattering of the wall	2 - 3

and their failure condition, while table 3-VII[1] includes the combined effects of both diffraction and drag phenomena upon target components as a function of distance from ground zero. The separate effects are indicated in figures 3-7[2] and 3-8.[2] Here the extent of severe damage from surface

1. Reference 1 in bibliography.
2. Reference 4 in bibliography.

Table 3-VII. Range of Blast Effects on Typical Target Elements Following a 1-MT Surface Burst

Peak Wind Vel. (mph)	Positive Phase Duration (sec)	Peak Dyn. Press. (psi)	Peak Over-Press. (psi)	Miles From G.Z.	Damage
				To about 18 miles	Window frames and doors: Light Damage. Plaster: Moderate Damage.
				To about 15 miles	Glass: Possible Breakage.
36	4.8	-	1.0	8	-
				7.5	Oil storage tanks, filled: Slight Damage.
43	4.6	-	1.2	7	-
				6.5	Fine kindling fuels: Ignited.
53	4.3	-	1.5	6	-
62	4.0	0.08	1.9	5	Wood frame houses: Moderate Damage. Radio and TV transmitting towers: Slight Damage. Smokestacks: Slight Damage.
83	3.8	0.13	2.4	4	-
				3.5	Light steel frame, light-walled industrial buildings: Moderate Damage. Motor vehicles: Slight Damage. Radio and TV transmitting towers: Moderate Damage. Wood frame houses: Severe Damage.
126	3.3	0.37	4.0	3	Medium steel frame, light-walled industrial buildings: Moderate Damage. Telephone and power lines: Limit of Significant Damage.
				2.5	Highway and R. R. truss bridges: Slight Damage. Steel frame, light-walled buildings (office type): Moderate Damage. Wood frame houses: Destroyed. Wall-bearing, brick buildings (apartment house type): Moderate Damage.
240	2.8	1.3	8.0	2	Reinforced concrete frame and walls, multistory structures: Moderate Damage. Wall-bearing, brick buildings (apartment house type): Severe Damage. Reinforced concrete light-walled frame buildings: Moderate Damage. Highway and R. R. truss bridges: Moderate Damage. Medium steel frame light-walled industrial buildings: Severe Damage.
				1.75	Reinforced concrete frame and walls, multistory structures: Severe Damage. Massive wall-bearing, multistory structures: Moderate Damage. Steel frame, light-walled buildings (office type): Severe Damage. Motor vehicles: Moderate Damage.
410	2.3	5.0	15	1.5	Oil storage tanks, filled: Severe Damage. Motor vehicles: Severe Damage.
680	1.6	15	30	1	Reinforced concrete, blast-resistant, windowless structures: Moderate Damage. All other structures: Severely Damaged or Destroyed.
				0	Ground zero

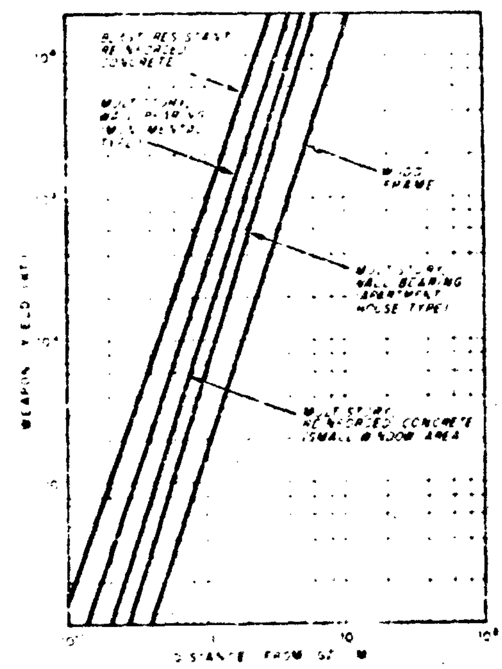

Figure 3-7. Range of Severe Damage to Diffraction-Sensitive Structures Due to Varied Yield of Surface Bursts.

detonations is given for structures primarily sensitive to overpressure and dynamic pressure, respectively.

In addition to the general blast effects shown in tables 3-VI and 3-VII, a great deal of damage may occur within structures. Blast pressures capable of causing roofs and/or walls to fall may also cause inner supports (beams, columns and bearing walls) to buckle. The entry of blast through wall openings can smash furnishings, rip doors off their hinges, and rupture frame members. The blast forces can also create destructive missiles from any article or fixture that will be trajected.

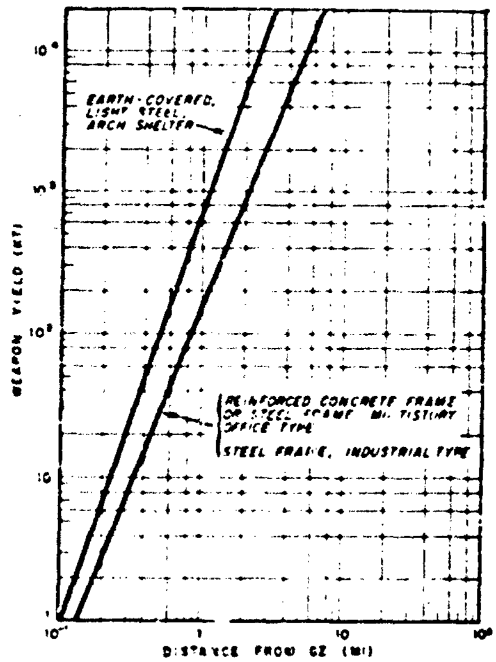

Figure 3-8. Range of Severe Damage to Drag-Sensitive Structures Due to Varied Yield of Surface Bursts.

c. Injury From Air Blast. The general interaction of a human body with a blast wave is somewhat similar to that of a structure. Because of the small size of the body, the diffraction process is quickly over and the body is rapidly engulfed and subjected to severe compression by the blast wave. This continues, with decreasing intensity, for the duration of the positive phase. The absorption of such punishment by the body may damage heart, lungs, stomach, intestines, eardrums[1] and cause internal hemorrhage. Experience with high explosives indicates that these injuries are

1. The air blast overpressure required to cause rupture of eardrums appears to depend highly upon circumstances. Several observations indicate that the minimum overpressure is in the range from 10 to 15 pounds per square inch, but both lower and higher values have been reported.

caused by peak overpressures of about 80 pounds per square inch, and that 200 to 300 pounds per square inch probably would be fatal.

When the pressure at the shock front increases rapidly or the positive phase lasts for an appreciable time (or both), serious blast injury (or death) can result at much lower peak pressures than when the pressure rises slowly or lasts for a short time. For example, tests indicate that a seven-fold increase in blast wave duration results in a three-fold decrease in the overpressure necessary to cause fatality in dogs. Since the positive phase of a nuclear blast wave lasts considerably longer than that for a conventional bomb explosion, peak overpressures much less than 200 or 80 pounds per square inch can be expected to cause death or injury, respectively.

Concurrently with the compression effects of the [illegible] wave, the drag forces due to the blast wind can cause translational displacement of the body. Resulting injury depends upon the force with which the body is thrown, the object it strikes, and its attitude at impact. The drag force is directly proportional to the frontal surface which the body presents to the blast wind. Thus, a person in a prone position would be much less affected than one standing up.

Perhaps more serious than direct blast injuries are the indirect effects due to collapsing buildings and flying debris. Wood splinters, pieces of metal and glass fragments in particular can penetrate up to an inch beneath the skin (and even through several layers of clothing). When fragments are small, clothing may provide some protection, otherwise a well-shielded position is required against the missile hazard. However, the likelihood of suffering fractures or being crushed and buried is greatest in or near conventional structures (i. e., not blast- and fire-resistant).

d. <u>Ground Shock</u>. In a nuclear surface burst a small proportion of the explosion energy is expended in producing a shock (or pressure) wave in the ground, of which only the general features are known at present. This shock wave differs from the blast wave in air in having a much less sudden increase of pressure at the front; also, it decays more sharply. Close to the explosion the pressure gradient is large enough to destroy the cohesive forces in the soil. The magnitude of the shock wave attenuates fairly rapidly with distance from the explosion, and at large distances it resembles that of an acoustic or seismic wave.

The effects of underground shock from a nuclear explosion have been described as being somewhat similar to those of an earthquake of moderate intensity, although there are significant differences between an underground nuclear burst and an earthquake. The pressure in the ground shock waves falls off more rapidly with distance in the case of the nuclear

explosion, and the radius of damage from a surface burst due to the ground shock (or "earthquake effect") is small in comparison with that due to air blast. For this reason, ground shock may be ignored where above-ground structures are concerned, since the blast effects are controlling.

The effect of ground shock pressure on an underground structure is somewhat different in character from that of air blast on a structure above the ground. Due to the similarity in density of the medium through which a ground shock wave travels and that of the underground structure, the response of the ground and the structure are closely related. The movement (acceleration, velocity, and displacement) of the underground structure by the shock wave is largely determined by the motion of the ground itself. Thus, relatively small underground structures can be expected to "roll" with the ground shock. The degree of damage to underground elements can be related roughly to crater radius (where the crater results from a surface or subsurface detonation). Table 3-VIII[1] presents some examples of this association for moderately deep underground structures. It can be seen that for either small and rigid or long and flexible structures there is no appreciable damage from ground shock beyond three crater radii. When structures are partly above and partly below ground, the damage to the latter portion will still be as shown in the table.

Table 3-VIII. Ground Shock Damage Criteria for Moderately Deep Underground Structures

Type of Structure	Distance From Surface Zero (crater radii.*)	Damage
Relatively small heavy, blast-resistant design (shelters).	1-1/4	Collapse or severe displacement.
	1-1/4 to 2	Shock damage to interior equipment.
	2 to 2-1/2	Severance of brittle connections, slight cracking at structural discontinuities.
Relatively long, flexible (pipelines).	1-1/2	Deformation and rupture.
	1-1/2 to 2	Slight deformation with some rupture.
	2 to 3	Failure of connections

*Crater radius for a 1-MT surface burst is about 700 ft depending upon soil conditions.

1. Reference 1 in bibliography.

3-03. THERMAL RADIATION. Because of the enormous quantity of energy released per unit mass in a nuclear weapon, temperatures of several million degrees are attained in the fireball. Thus a significant fraction of the nuclear energy is given off in the form of heat. The transmission of heat energy from a high temperature source is termed thermal radiation.

Although blast is responsible for most of the initial destruction caused by a nuclear burst, thermal radiation contributes to the overall damage by igniting combustible materials. Finely divided or thin fuels such as dried leaves and newspapers ignite easily and start fires in buildings or forests. These fires may spread rapidly among the debris produced by the blast. In addition, thermal radiation is capable of causing skin burns on exposed individuals at distances from the nuclear explosion where blast and initial nuclear radiation may not be significant. This difference between the injury ranges of thermal radiation and of the other effects mentioned becomes more marked with increasing energy yield of the explosion (refer to figure 3-12).

For all types of bursts the severity of thermal effects (charring and ignition of materials and production of skin burns) is, in general, dependent upon the irradiance or rate at which the radiant energy is delivered. As weapon yield increases, the thermal energy is delivered over a longer period of time, hence at lower irradiance levels. Therefore, the total amount of thermal energy required to produce a particular effect increases with weapon yield.

a. General Properties. Thermal radiations are made up of ultraviolet rays of short wave length, visible light of longer wave length, and infrared radiation of still longer wave length. Thermal radiation travels with the speed of light so that the time of transmission to a target is negligible.

An inverse square reduction in thermal radiation intensity occurs which is enhanced by atmospheric attenuation. The amount of thermal radiation from a particular nuclear explosion that reaches a given point depends upon weapon yield, distance from the burst, and condition of the intervening atmosphere. Scattering caused by molecules of oxygen and nitrogen in the air is relatively unimportant compared to that created by such atmospheric pollutants as dust, smoke and fog.

Unless scattered, thermal radiation from a nuclear explosion, like ordinary light, travels in straight lines from its source, the fireball. Any opaque material between a given object and the fireball acts as a shield and provides protection from thermal radiation. Transparent materials, such as glass or plastic, allow thermal radiation to pass through only slightly attenuated. A shield which merely intervenes but which does not surround the target, as would a wall or hill, may not be entirely effective under many atmospheric conditions. A large proportion of the

thermal radiation received, especially at considerable distances from the explosion, undergoes scattering and arrives from many directions.

b. Dependence Upon Detonation Height. The foregoing discussion has referred in particular to thermal radiation from an air burst. For other types of burst the general effects are the same, although they differ in degree. For a surface burst, when the ball of fire actually touches the earth's surface, the thermal energy radiating beyond the fireball is less than for an air burst. This is due to a portion of the thermal radiation being obscured by debris rapidly rising from the ground. Less thermal energy is so lost as the height of burst increases.

In the case of a surface burst, most of the thermal radiation reaching a given target on the ground has traveled through the air near the earth's surface, where the extent of scattering by dust particles is greater than at higher altitudes. Consequently, in addition to less thermal energy being radiated in the case of a surface burst, a still smaller amount reaches the target at a specified distance from the explosion. The thermal effects of a surface burst thus are significantly less than for an air burst of the same total energy yield. This is demonstrated in figure 3-9.[1]

In subsurface bursts, either in the earth or under water, nearly all the thermal radiation is absorbed, provided there is no appreciable penetration of the surface by the ball of fire. The thermal energy is used up in heating and/or vaporizing the soil or water; and thermal radiation effects that would accompany an air burst are thus absent.

c. Incendiary Effects. When thermal radiation strikes a surface, the energy absorbed produces heat. If the irradiance is very high, this absorption occurs in a very shallow layer of the material resulting in extremely high temperatures at the surface of impingement. The most important physical effects of such temperatures are burning skin, and scorching, charring, or igniting combustible substances.

Ignition by thermal radiation depends upon a number of factors concerning the material and its condition. For example, transparent or reflective surfaces are affected to a far lesser extent than are opaque or darkly colored surfaces. Thin materials such as newspaper, dried leaves and grass, and porous materials such as rotted wood, generally ignite and sustain flame when exposed to thermal radiation. Thick materials, for example wood more than 1/2 inch thick, plastics, and heavy fabrics, ignite and char but do not continue to burn. Dense smoke and volumes of flame may be emitted, but the material does not sustain ignition after the radiation falls below a certain level.

Table 3-IX lists a number of materials found on the exteriors of conventional structures. The damage effects are shown with the radiant

1. Reference 4 in bibliography.

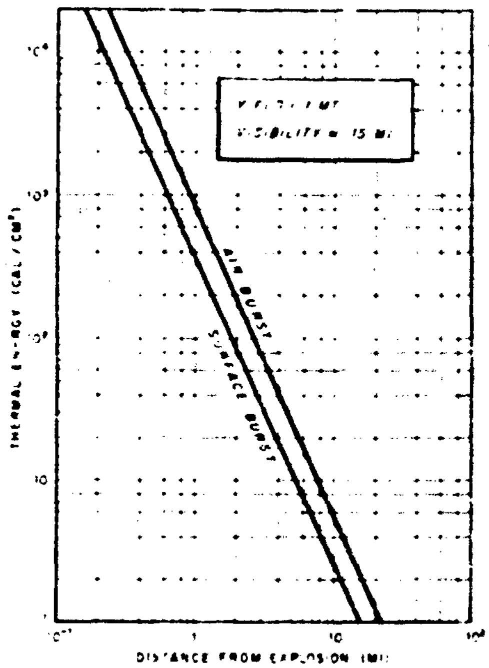

Figure 3-9. Comparison of Thermal Energy Ranges for 1-MT Air and Surface Bursts.

energies required to produce them. By using this information in conjunction with the family of thermal energy curves shown in figure 3-10[1] it is possible to determine approximately how far from the explosion center thermal damage may occur for various weapon yields.

It is obvious from table 3-IX that miscellaneous trash is the most prone to ignition. The remaining materials sustain damage but are not likely to start self-supporting fires. Being combustible, however, they can contribute to fires less directly, but nonetheless effectively, as fuels. Thus the kindling materials are responsible for the origin of a fire, and the less combustible materials are responsible for its growth and spread. If, in a built-up area, these materials are present in the

1. Reference 4 of bibliography.

Table 3-IX. Thermal Damage Sustained by Various Building Materials[1]

Material	Damage	Critical Radiant Exposure (cal/cm^2) KT Range	Critical Radiant Exposure (cal/cm^2) MT Range
Wood, Yellow Pine	Flames during exposure	20	40
Wood, White Pine	0.1 mm depth char	10 - 20	30
Plywood, Douglas Fir			
1/4 in.	Flames during exposure	9 - 15	20 - 35
3/8 in.	Flames during exposure	20	40
Roll Roofing			
mineral surface	Surface melts	8 - 15	25
	Flames during exposure	20 - 40	55 - 70
smooth surface	Surface melts	4 - 7	10
	Flames during exposure	9 - 15	20 - 30
Paint, Fire-Resistant, white, 1 coat on			
1/4-in. plywood	Flames during exposure	20	-
1/32-in. sheet steel	Chars	60	-
Protective Coating on White Pine	0.1 mm depth char	40 - 70	125
Awning, Canvas, O.D.	Sustained ignition.	14	20 - 40
Miscellaneous Trash - Including newspapers, rags, paper cartons, excelsior, oily waste, leaves, grass, etc.	Sustained ignition.	3 - 15	15 - 40

1. References 4, 38 and 39 in bibliography.

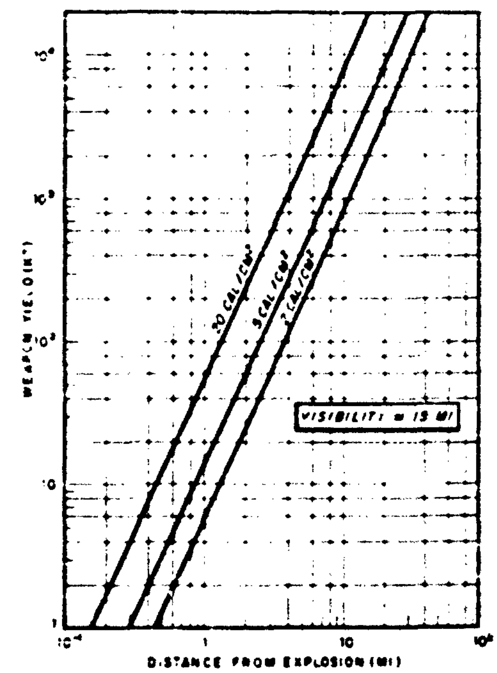

Figure 3-10. Thermal Energy Received at Various Distances From Surface Bursts.

proper proportions, the thermal radiations from a nuclear attack (especially air burst) will start many isolated blazes which may quickly combine into a gigantic fire.

Under certain conditions there may develop what is known as a fire storm. This phenomenon is characterized by increasing winds whose maximum velocities may reach 60 to 100 miles per hour. They are an out growth of the draft caused by the rapid rise of heated air over an extensive burning area. Providing there is ample fuel, these winds fan the flames to such an intensity that the resulting fire storm consumes virtually everything combustible within its reach.

d. Injury to Personnel. Thermal radiation can cause burn injuries either directly by absorption of the radiant energy by the skin, or indirectly as a result of fires started by the radiation. The direct burns are called flash burns, since they are produced by the flash of thermal radiation from the fireball. The indirect burns are referred to as flame burns and are identical to those caused by any large fire regardless of its origin.

Although the depth or degree of the burn is an important factor in determining its effect on the individual, the extent of the area involved must be taken into consideration. Thus, a first-degree burn over a large area of the body may produce a casualty, and an extensive second-degree burn usually incapacitates or kills the victim. For this reason, all persons exposed to thermal radiations of sufficient energy to cause second-degree flash burns are potential casualties. The curves in figure 3-11[1] indicate the range at which first and second-degree burns may be expected for surface bursts of varying yields.

3-04. SUMMARY. A minimum of detail concerning the various effects of nuclear weapons has been presented in this section. The more technical aspects involving the theories of blast, thermal and radiation phenomena have been purposely avoided. It has been the intention of this section to familiarize the reader with the above effects and to indicate their approximate magnitude. In all cases these effects, as related to people and structures, have been shown to be a function of weapon yield, weather, height of burst, and distance from the explosion.

By way of review and for easier comparison, the significant magnitudes of the three basic weapon phenomena (blast, heat, and initial radiation) have been plotted in figure 3-12. The resulting curves depict the immediate effects as a function of distance from ground zero for various-sized surface detonations. A study of the curves demonstrates that for yields of 20 kilotons or more the lethal range of prompt gamma radiation and neutrons lies within the region of significant blast damage. Further, the range of immediate thermal effects is greater than that of either blast or radiation and becomes even more so with increased weapon yield.

Of major importance, however, from the standpoint of protective construction (as defined by this handbook), is the wide-spread residual effects of radioactive fallout discussed in section 3-01. The inclusion in figure 3-12 of curves for these effects is not possible, since the fallout event and the attendant radiations are functions of time. It suffices to say that, depending upon the weapon yield, wind conditions and detonation environment, fallout in significant quantities may exist for hundreds of miles beyond ground zero; and the gamma radiation hazard may last for months and for as much as two years in the region of heaviest fallout.

1. Reference 4 of bibliography.

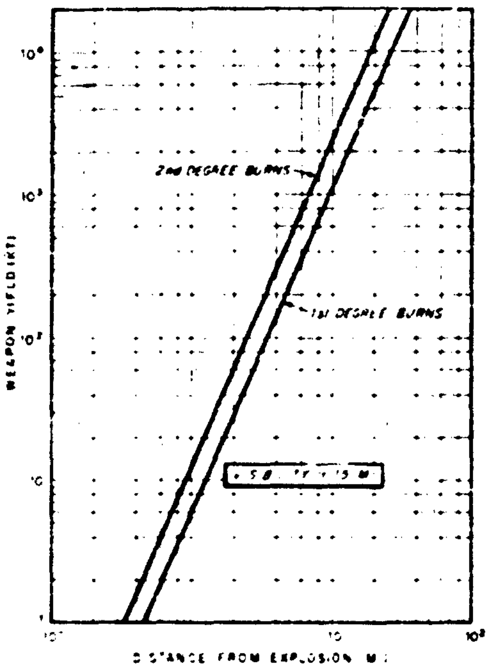

Figure 3-11. Range of Serious Skin Burns Due to Thermal Radiation From Surface Bursts.

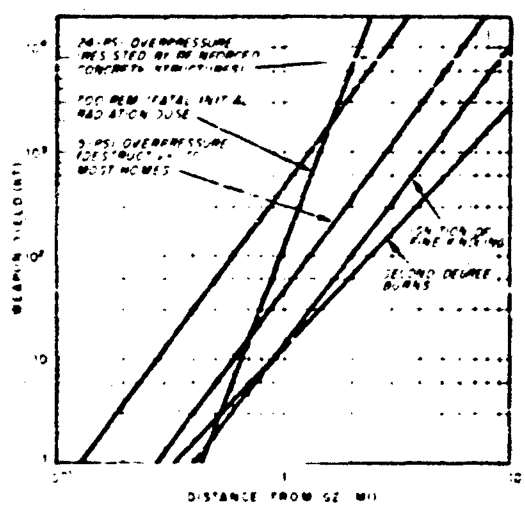

Figure 3-12. Immediate Effects of a Surface Burst as a Function of Yield and Distance.

SECTION IV - PRINCIPLES OF PROTECTION FOR FACILITIES AND PERSONNEL

4-01. BASIC OBJECTIVES OF FALLOUT PROTECTION. The importance of fallout and the need for an appropriate defense against its effects have been established in section I. The problem (the major objective of this handbook) remains to develop realistic means for accomplishing fallout protective construction. In its simplest terms, resisting the effects of fallout requires filtering out the more harmful radiations and/or removing fallout as the radiation source. Where protection of structures and their staffs are concerned, fallout resistance involves fulfilling one or more of the following objectives:

1. Improving the inherent shelter effectiveness of structures.
2. Minimizing the deposition and retention of the fallout.
3. Facilitating the removal of the contaminant.

These objectives can be attained through the implementation of certain basic principles of protective construction which are discussed below. In addition, some degree of improved protection against blast and thermal effects may be realized in many instances. These bonus benefits are discussed in sections 4-06. and 4-07. of this Section.

4-02. ATTENUATION OF GAMMA RAYS. As implied in the first objective above, all closed structures are capable of weakening (attenuating) the intensities of incident gamma rays, the primary injury-producing mechanism of fallout. For example, about 50 percent of the radiation due to fallout on and around a typical wooden barrack reaches the occupants. Improving this inherent resistance of structures is of great importance to protective construction. The amount of improvement is a direct function of the two factors which lessen radiation in general, namely:

1. Shielding or filtering out the rays with absorbant materials.
2. Keeping the receiver at a distance from the radiation source.

Taken together, shielding and distance comprise shelter effectiveness.

a. Shielding Protection. Gamma rays are absorbed (or attenuated) to some extent when they pass through every material. Except in unusual circumstances, the decrease in radiation intensity depends upon the mass of material that intervenes between the radiation source and the receiving point. A greater thickness of a less dense substance (wood) than one of high density (metal) is required to attenuate the radiations by a specified amount. Although an extravagant amount of barrier material may be required, to absorb gamma rays completely, a reasonably thick or dense shield can greatly reduce the exposure dose to an individual.

The shielding effectiveness for a given thickness of a material can be expressed in terms of the "fractional intensity". This is the ratio I/I_0; where I_0 is the intensity of a parallel beam of gamma rays directed normal to a slab absorber, and I is the fraction of I_0 penetrating the slab or shield. A low fractional intensity (<< 1) signifies that a shield is a strong absorber of gamma rays. Figure 4-1 shows the variation in shielding effectiveness (fractional intensity) with thickness for several common materials, when exposed to gamma rays of an energy typical of fallout (0.5 million electron volts). For comparison, figure 4-2 is included to show that a similar relationship exists when the incident radiation is of higher energy (4 million electron volts) as associated with initial radiation. In this case, a thicker and/or denser material is required to achieve a given fractional intensity than when shielding against energies in the same range as fallout radiation. In any case, protective construction should employ heavier walls, roofs, floors, and partitions. This means using denser materials and selecting more massive designs for building members.

b. Distance Protection. In addition to direct shielding, gamma rays are attenuated with increased distance from the radiation source. For a uniformly distributed source, such as a fallout field, the area nearest the receiver contributes the most radiation. This is depicted in figure 4-3. for a receiving point 3 feet above the surface. It is also apparent from the figure that the percent contribution of the contaminated surroundings to the radiation field at the receiver decreases with distance. The rate of this decrease or attenuation is demonstrated by the steep slope of the distance protection curves of figure 4-4.[1] Again, the attenuation is given in terms of fractional intensities. In either case, fractional intensity indicates what portion of the total available radiation actually reaches a particular location.

Both figures 4-3 and 4-4 indicate that unpaved areas provide more protection at a given distance than do paved areas. The added attenuation is due to the combined effect of distance plus shielding. The roughness of unpaved surfaces partially blocks the radiations coming from fallout material lying in depressions or behind protuberances.

Thus, the radiation intensity existing above a contaminated plane can be significantly reduced by providing moderately-sized clean areas in the immediate vicinity of the receiving point. Employing this principle in protective construction means altering the size and shape of buildings so as to form a more continuous and distant envelope about the uncontaminated interior.

c. Scattered Gamma Radiation. In its passage through the atmosphere, gamma radiation, like thermal radiation, is scattered by particles present in the air. Even though most of the radiation will be received along a direct "line of sight" from the source, scattering will cause a certain portion to arrive from oblique directions, as shown in figure 4-5.

1. Reference 5 in bibliography.

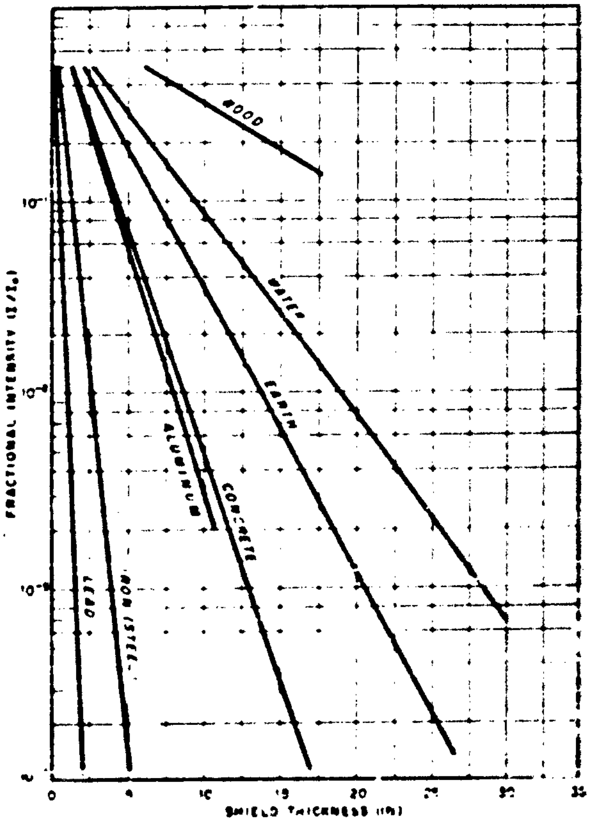

Figure 4-1. Attenuation of Low Energy Radiation as Typifies Fallout (0.5 Mev) for Various Thicknesses of Material.

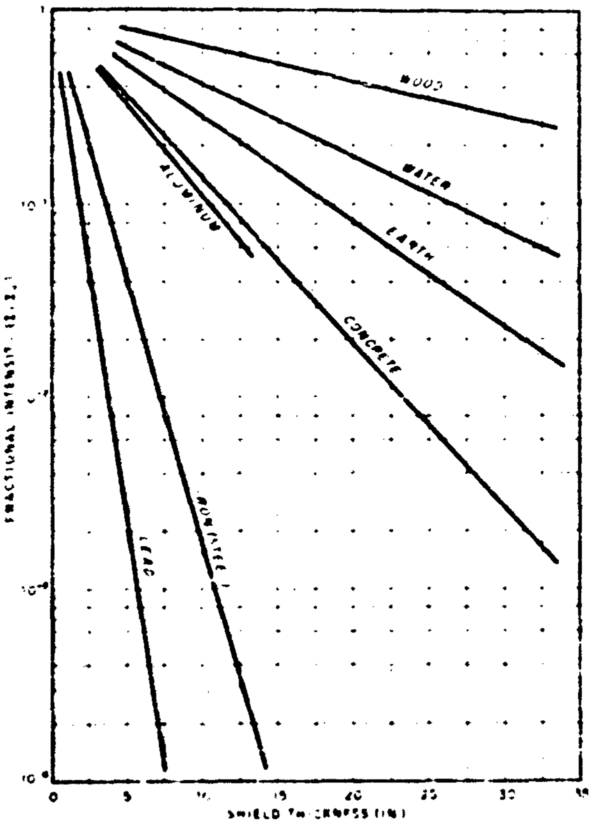

Figure 4-2. Attenuation of High-Energy Initial Radiation (4 Mev) for Various Thicknesses of Material.

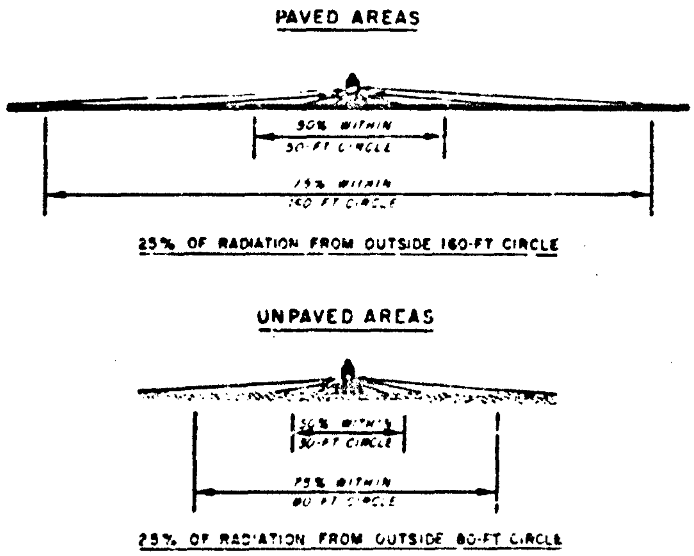

Figure 4-3. Relative Contribution of Contaminated Areas to Central Radiation Intensity at 3 Feet Above Surface.

Consequently, shielding must be provided on all sides of a receiver in order to furnish complete protection. Scattered radiation is always less energetic than direct radiation; hence, it is easier to shield against.

4-03. REDUCTION OF FALLOUT DEPOSITION AND RETENTION. The protection which a facility affords can be improved by making it more difficult for fallout material to be deposited and to remain on its exterior surfaces. The contributing factors affecting deposition and retention of fallout particles consist of three main categories:

1. Fallout properties (physical and chemical) such as type of carrier material (see table 3-IV), density, particle size, and phase which influence the manner of arrival and the tenacity of adherence to a surface.

2. Weather conditions such as precipitation, temperature, and especially wind velocities which control the initial distribution of contaminated particles and their possible resuspension and/or redistribution.

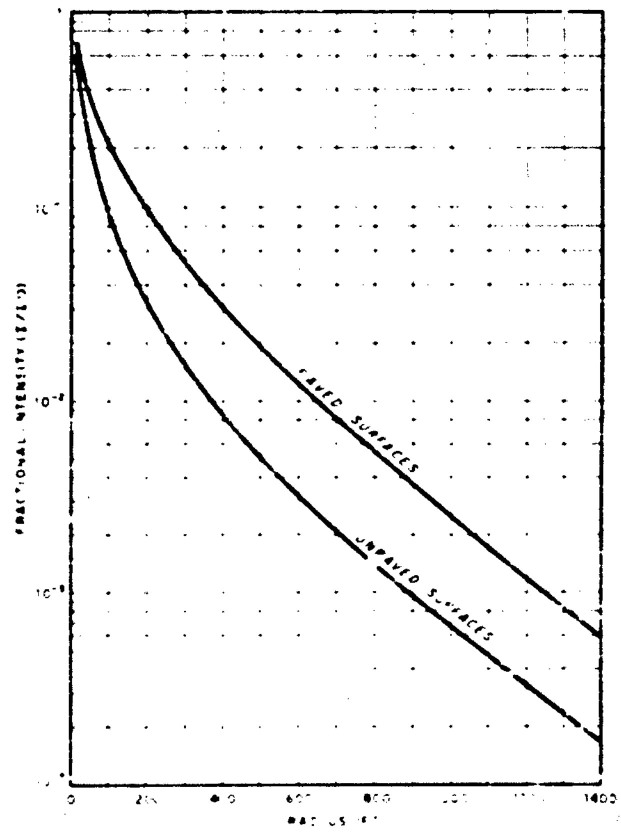

Figure 4-4. Effectiveness of Distance in Reducing Fallout Radiation, as Observed 3 Feet Above a Clean Circular Area Surrounded by a Uniformly Contaminated Infinite Plane.

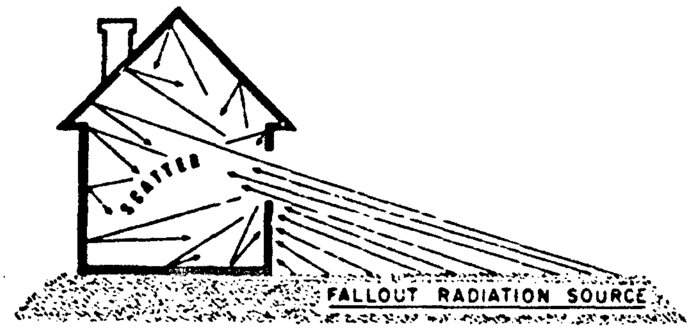

Figure 4-5. Schematic Representation of Scattering Phenomena.

3. *Target vulnerability* (in a radiological sense only) including: (a) the general orientation of exterior surfaces which determine the air flow pattern around buildings and affect the drainage and weathering of fallout material from surfaces; and (b) the detailed surface conditions which influence retention of contaminant.

Any alteration in factors belonging to the first two categories will depend, to a large extent, upon the enemy's decision regarding the weapons used, the target selected, and the conditions of attack. Therefore, the active concern of radiological defense is with the third category which involves minimizing the contaminability of the target. Thus, the architectural and construction characteristics of building complexes will greatly influence target vulnerability.

a. *Simplified Geometry*. Because of the "flight" characteristics of airborne particles, their tendency to deposit out is aggravated by abrupt changes in direction of the air flow. Buildings whose exterior geometries create air turbulences would collect more fallout material than those that encourage the smooth swift passage of air. Projections and voids, then, should be minimized or eliminated altogether to attain a more aerodynamic configuration. Streamlining would also provide better drainage characteristics for the removal and transport of collected material.

In order to take full advantage of a building's aerodynamic features, it should be correctly oriented with regard to the prevailing winds. That

is, it should be placed so as to present the least wind resistance. For the same reason, buildings should be properly located and spaced with respect to each other. Because of the lack of information concerning the complex aerodynamic influence of one building upon another, an exaggerated clearance between buildings may be the most effective arrangement.

b. Vertical Versus Horizontal Areas. Horizontal target surfaces generally become more contaminated than vertical surfaces when subjected to a dry non-tenacious type of fallout. Measurement of test structures contaminated by a land detonation has revealed radiation levels on roofs which exceed those on adjacent walls by factors of 100.[1] There is no guarantee that heavier fallout concentrations (100 grams per square foot or more) would not produce even greater horizontal-to-vertical contamination ratios.

On the basis of the above information the avoidance of unnecessary horizontal areas is obvious. Surfaces such as ledges and window sills may be eliminated without detriment to structural design. Roofs and ground areas, the main recipients of fallout material, are still indispensable and must be tolerated. However, providing a prominent slope to these surfaces would encourage the migration of fallout particles under the natural action of the elements (wind and rain) or that of radiological recovery (reclamation).

Horizontal-to-vertical relationships are not particularly pertinent to targets near major bodies of water, where a wet type of contaminant is likely. Experience has shown that, because of its liquid nature and small drop size, fallout from detonations in or near water is highly capable of adhering to any surface on which it impacts - regardless of orientation. Providing the relative wind velocity is sufficient, contamination of vertical surfaces in a given location can equal or exceed that of relatively horizontal areas.

c. Improved Materials. Another aspect of target vulnerability to fallout concerns the physico-chemical characteristics of construction materials. Roughness, porosity, wettability, adsorption capabilities, and chemical reactivity are all surface properties that can favor fallout retention. The same properties are also responsible for the degree to which contaminant can be loosened, removed and transported by weathering and decontamination processes. Therefore, to reduce contaminability, materials should be smooth, hard, water-repellent and chemically inert.

Few materials, if any, exhibit all of these properties. Fortunately, where dry fallout is anticipated, smoothness is the most important factor. If fallout is of the wet type, impermeability and inertness are controlling. In either case, it is often possible to achieve all three of these surface conditions by the application of a suitable coating. The contaminability

1. Reference 6 in bibliography.

of a given material may be reduced by a protective film which seals pores, smooths rough surfaces, and imposes a barrier between the base material and fallout particles. In this way a suitable coating can reduce the degree of fallout entrapment that would otherwise occur on an unprotected surface.

It should be pointed out that some coatings may impair the function of a surface by making it too slippery for bearing traffic when wet, less fire-resistant, or more expensive to maintain. Furthermore, available paints, lacquers and sealers do not as yet provide the desired degree of protection to all building materials currently in use.

d. Smooth Surface Systems. The general configuration of a surface in many instances is more important than the intimate surface characteristics. This is true when numerous seams and cracks occur at the junctures of exterior construction materials. Spaces between shingles and the recessed, porous mortar-joints between bricks are typical examples of collection points for fallout particles.

The designer of a protective structure is faced with the problem of giving it a smoothly surfaced exterior having no weak structural points. Revamping of present surface systems toward reducing or eliminating fallout retention points is no simple matter. Substitution of materials is probably the most promising approach.

4-04. FACILITATION OF FALLOUT REMOVAL. No matter how rigorously an installation is designed to reduce contaminability, a certain amount of fallout will be deposited and retained. In some instances the concentrations may result in critical radiation levels. Because there is no method of neutralizing radioactivity, such deposits of contaminant must be physically removed to less sensitive areas (or shielded in place).

The removal process consists of a variety of fairly straightforward techniques such as:

1. Washing fallout deposits off the surfaces and into gutters and drainage systems with firehoses and street flushers.

2. Picking up and collecting fallout material with street sweepers.

3. Burying fallout in place with plows or new earth fill.[1]

4. Removing soil plus fallout with earth-moving equipment.

These are the principal ways to rid a given surface of fallout.

1. Although not a true removal process, burial is an effective means of reducing the radiation levels due to fallout. It therefore falls in the more general class of reclamation which includes both removal and burial methods.

The summation of post-attack measures, including fallout removal, to restore a contaminated facility or target complex is termed the radiological recovery. Recovery has two facets: the effectiveness with which it reduces dose by removing contaminant; and the cost measured in terms of operating time, manpower or effort, radiation exposure, and equipment and supplies. Cost and effectiveness influence each other and the achieving of recovery in a number of ways:

1. The effectiveness must be great enough to reduce the radiation dose rate to the required level.

2. The dose to recovery crews will limit the length of time devoted to achieving a certain effectiveness.

3. The radiation exposure of recovery personnel must be justified by reduced exposure of mission personnel.[1]

4. The effort (manpower) and logistics required to reclaim the installation must be compatible with the total effort available.

Achieving high effectiveness at reasonable cost is possible by observing principles of protective construction which facilitate radiological recovery. Those characteristics which make targets and their materials less contaminable also improve their decontaminability. Because of this complementary arrangement, the principles already discussed under target vulnerability (in section 4-03.) are equally applicable to facilitating reclamation. However, there are several other important factors that should be considered.

a. Drainage. A complete decontamination process, after removing fallout from a sensitive area must allow for its transportation to a disposal point, such as a storm drain or sewer. It is highly desirable to use a procedure in which the act of dislodging particles also carries them all the way to the disposal area; rather than having them recontaminate an adjacent area and require subsequent removal. If water is used as the decontaminating media, it may also be used to transport the disturbed particles, provided proper drainage conditions are established.

There are two principal factors in the design of a drainage system: first, the slope of the channel; second, the cross-sectional shape of the channel. The most efficient transport is provided by deep channels that achieve high-velocity turbulent flow. Maximum settling and redeposition results from thin water films moving at low velocity. Therefore, slopes should be great enough to establish a positive (and preferably a high-velocity) flow regardless of construction variables. An adequate slope to roofs and the areas next to buildings is an important feature of a well-

1. Personnel who will carry on the function of the facility once it is restored.

integrated drainage system. Since run-off water collecting in surface depressions causes considerable difficulty during decontamination, they should be eliminated.

Rainfall is capable of performing decontamination. However, it may not be very effective unless the target is designed with this in mind. Again, controlled drainage conditions are a basic requirement.

b. Accessibility and Services. In lieu of automatic systems, the best method for decontaminating roofs is by firehosing. Effective recovery frequently requires that crews work directly on the contaminated roof surface. Consequently an exterior access to the building roof should be provided. Built-in headers to allow hose connections at roof level will eliminate long runs of hoses which otherwise would have to be lifted from street level.

As indicated previously, it is important to keep recovery operations as inexpensive as possible. Where ground areas are concerned, this is done with mechanized equipment. For a given effectiveness, firehosing a paved area costs fifteen[1] times as much manpower (man hours) and ten[2] times as much radiation exposure as motorized flushing the same area. In a general way, motorized graders and men using hand shovels can be compared similarly. Therefore, areas surrounding essential buildings should be designed so as to permit use of the most efficient type of equipment.

Operation of street sweepers, trucks and other large rigs require greater spacing between buildings than is normally found. Outbuildings, fences, poles, and other obstructions to the maneuverability of equipment must be minimized or deleted. Roll curbs unobstructed by lamp posts, service poles, and hydrants will permit the use of street flushers on sidewalks. For similar reasons, ramps are preferred over steps. In all cases, paving must be strong enough to bear rolling stock.

Although a number of effective decontamination methods are applicable, those employing water, such as firehosing and motorized flushing, are generally more available. For this reason, the demands on the water supply to a target complex may rival those experienced when fighting fires. The factors which will tend to increase the reliability of the water supply system are discussed under Improved Fire-Fighting Capability section 4-06.,c.

c. Special Devices. Means for automatic reclamation of a facility is desirable in order to: (1) maintain continuous operations through the fallout period without sacrificing the staff or crew, (2) further reduce the dosage to those manning the facility in lieu of or in addition to providing shielding.

1. Reference 7 in bibliography.
2. Reference 8 in bibliography.

radiations are responsible for this chemical action. The amount of ionization or number of ion pairs produced by the radiation would thus provide a basis for its measurement. Although the full definition is somewhat more involved, the roentgen is defined in terms of the number of ion pairs formed in 1 gram of air due to the passage of gamma radiation or X-rays. A dosage of 1 roentgen results in the absorption of about 87 ergs of energy per gram of air due to the passage of gamma radiation or X-rays.

The roentgen is a measure of the amount of ionization in air at a given location, rather than of the radiation absorbed by an individual at that location. The radiation dose in roentgens is thus referred to as an "exposure dose". In order to distinguish this from the "absorbed dose" (pertaining to tissue) another unit is required. One such unit is the "rad". It is defined as the dose associated with any nuclear radiation which is accompanied by the absorption of 100 ergs of energy per gram of material. Since a dosage of 1 roentgen results in the absorption of about 97 ergs per gram of soft tissue, the difference between numerical values of the roentgen and the rad is insignificant.

Two types of measurement, both of which have important uses, are made by radiation instruments. Some record the total radiation dose (or amount) in roentgens received during an exposure period. Others indicate the dose rate expressed in roentgens per hour or, for smaller dose rates in milliroentgens per hour (a milliroentgen is one thousandth of a roentgen).

c. Gamma Radiation Hazard. Because of their ionizing power, sufficient exposure to gamma rays may cause serious illness or death. The magnitude of radiation sickness and the speed of onset depend principally upon the total dose received. However, dose rate, exposure sequence, and length of exposure are also influencing factors.

Biological effects of ionizing radiation are usually spoken of as being either acute or delayed. Acute effects are those occurring within approximately one month of radiation exposure. Delayed (or late) effects are those occurring months or even years after exposure. Leukemia, cancer and shortening of the life span are some of the possible late effects.

Table 3-III[1] shows acute effects predicted for various dosages. The exposure time for all dosage ranges given is between 24 hours and one week. The human body is known to have a limited ability to repair radiation damage. Because this recovery factor is not significant during a prolonged exposure period of one week, its effects are not reflected in table 3-III.

d. Dose-Distance-Weapon Yield Relationships. The magnitude of the dosage from the initial nuclear radiation depends upon weapon yield

1. Reference 2 of bibliography.

The washdown system, already proven in the protection of ships, can also be used to decontaminate building roofs. As its name implies, washdown flushes away fallout, immediately upon arrival, through the flooding action of numerous water sprays. Since washdown can be activated prior to the fallout event, it will prevent the build-up of contaminant on roof surfaces. In this way washdown reduces the dose rate earlier than manual decontamination methods can.

Another system of fallout protection for structures employs disposable surfaces. This may consist of a canvas cover that rolls up like a window shade, or it may merely be a strippable coating. The former could be actuated automatically; the latter would have to be removed by manual decontamination. Paints that are capable of being stripped by mild alkaline solutions have been developed for smooth metal surfaces.

d. Land Area Reclamation. Many installations are closely surrounded by unpaved areas, i.e., unimproved ground, fields, graveled areas, oiled dirt, and landscaped grounds such as lawns, flower beds, etc. The basic methods of reclaiming land areas in order of increasing effectiveness are: mixing by disking or rototilling, burying by plowing or filling, and removing surface layers by grading, scraping etc. The success of the latter technique is due to the transport of the fallout (along with the surface material over which it was distributed) away from the area to a remote disposal point. Many kinds of equipment are available for soil removal, but the two most suited for this purpose are the motorized grader and the motorized scraper.

Successful land reclamation is dependent upon the soil conditions and the terrain characteristics. Generally speaking, a smooth flat terrain and a soft, moist, cohesive pliable soil are characteristics conducive to effective decontamination. Only a very thin (2 inch) layer of such a soil need be removed.

Factors that would obstruct effective reclamation are uneven terrain that causes spills, rocks that leave voids when removed and interrupt smooth equipment progress, uncompacted soils that provide poor loading characteristics, and dry soils that enhance resuspension and spills. Under these conditions deeper cuts and repeated operations are necessary in order to obtain appreciable effectiveness. Deep-rooted stringy plants that do not pull free with a shallow cut cause local spills. Shallow-rooted vegetation, which serves as a surface binder only, cuts freely and also prevents the cut sod from breaking up, thereby facilitating removal. Finally, large shrubs and trees obstruct the progress of motorized equipment and the reclamation operation and should, therefore, be minimized.

4-05. INTERACTION OF SHELTERING AND RECOVERY. The preceeding sections have introduced many protective principles for lessening the potential threat of fallout to the occupants of buildings. Although

discussed individually, obviously the various principles do not work independently but are interrelated. The complementary relationship between reducing target vulnerability and facilitating radiological recovery was noted earlier. Equally important to the performance of protective construction is the interaction of shelter effectiveness with that of reclamation.

The full significance of this relationship becomes clearer after first visualizing the emergency situation precipitated by a contaminating nuclear attack. It must be assumed that, upon receipt of warning or during the actual attack, personnel will seek the physical protection of the nearest structure. The presence of fallout will require an extended period of stay within these shelters after termination of the attack. In areas of high radiation intensity, stay times will be proportionately long. Under such conditions, the earlier observance of the principles of shielding and distance protection (which comprise shelter effectiveness) will reduce the accumulated dose.

Eventually personnel must emerge from cover to initiate the recovery operation. If the protective principles which permit the efficient performance of such an effort have been obeyed, the dose to recovery and mission personnel will be further reduced, and shelter stay times may be appreciably shortened. In this way, the protective principles responsible for the reclamation effectiveness of an installation exert a controlling influence upon the shelter effectiveness. Figure 4-6[1] demonstrates this interaction with a family of paired curves for maximum permissible exposure (MPE) of 100 roentgens and 150 roentgens respectively, occurring during the first year following a contaminating event. Each pair of constant exposure curves is plotted for a different radiation field intensity.[2]

The many ramifications of such a plot are best understood by studying one curve at a time. Choosing the uppermost curve at a standard intensity of 300 roentgens per hour, the maximum permissible exposure (for the first year) may be held to 150 roentgens by staying two days in a basement or multistoried building, if the dosage reduction (effectiveness) by sheltering is between 0.01 to 0.001 and that due to reclamation is 0.25, respectively. Where shelter effectiveness is not as great, the recovery effectiveness must necessarily increase. For instance, a one-story concrete building whose sheltering effectiveness is only 0.1 requires a recovery effectiveness of 0.15, in order to not exceed the stipulated maximum permissible exposure and stay time.

1. Reference 9 in Bibliography.
2. The radiation dose rates (roentgens per hour) are all shown at a common time of one hour after burst and, as such, are called "standard intensities". Presenting the levels in this way provides a convenient basis for comparison. The values shown were arbitrarily chosen, but standard intensities may be obtained from existing levels by extrapolating the corresponding decay curves back to one hour as shown by the dashed line in figure 3-4.

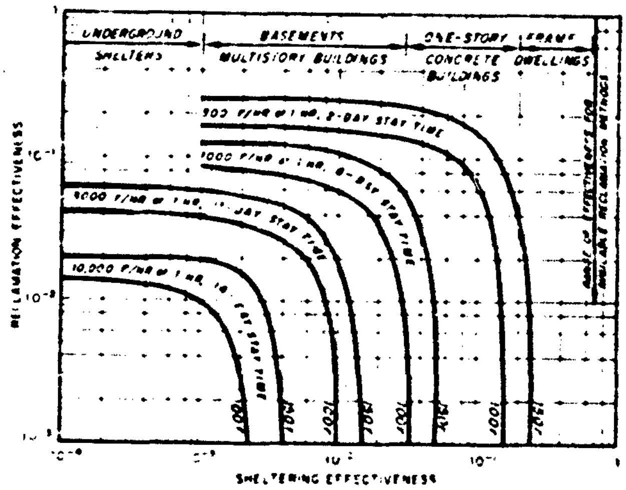

Figure 4-6. Relationship Between Shelter and Reclamation Effectiveness for 100-roentgen and 150-roentgen Dose in 1 Year.

The other curves are interpreted similarly, but because of the increase in standard intensities, the stay times and the respective effectivenesses needed become progressively greater. At the same time, the choice of protective types of structures diminishes. One-story concrete buildings (and frame dwellings, of course) are shown to be inadequate for standard intensities of 3000 roentgens per hour and greater. This would be true, for stay times of 11 days or more, even if the contribution by recovery was beyond all practical limits - as indicated by the steep downward trend in the curves. The horizontal portions of the curves indicate that there will always be a minimum reclamation requirement, even for underground shelters.

A set of curves such as those in figure 4-6 is of great value in demonstrating the interdependence of shelter specifications and reclamation requirements. Had different maximum permissible exposures, stay times, or standard intensities been selected, the curves would have changed only in magnitude but not in their characteristic form.

4-06. PROTECTIVE BENEFITS AGAINST HEAT AND FIRE. As pointed out earlier in this Section, many of the principles based on radiological

considerations also provide, in varying degrees, some increased protection against the more immediate blast and thermal effects. From the data in figure 3-12 and table 1-I, it is clear that the range of serious thermal effects may reach beyond the zone of physical destruction. Since the above principles find their greatest application in the regions outside this zone, they can also be used, for the most part, to lessen the danger from heat and fire.

Although the flash of thermal energy accompanying a nuclear detonation may be injurious or lethal to exposed personnel, simple shielding will offer sufficient protection. Of far greater consequence, however, are the incendiary effects that soon follow. There are two general ways in which fires can originate in a nuclear explosion. First, the ignition of paper, trash, window curtains, awnings, excelsior, dry grass, and leaves, could result directly from the absorption of thermal radiation. Second, indirectly from the destruction caused by the blast wave, fires can be started by upset stoves and furnaces, electrical short-circuits, and broken gas lines. No matter how the fire originates, its subsequent spread will be determined by the amount and distribution of combustible materials in the vicinity.

The potential for initiating fires by thermal energy in a given location may be expressed in terms of the "density of ignition points". This refers to the frequency of combustible materials which might be expected to ignite when exposed to 3 to 5 calories per square centimeter of radiant energy.[1] A typical distribution of ignition points per acre in large American cities is presented in figure 4-7.[2] The incidence of primary ignition points at military stations should differ little from the neighboring communities. It should be understood that the graph merely indicates the relative chances of fires originating in various parts of a city. The formation of significant fires, capable of spreading, requires appreciable quantities of combustible materials nearby. For this reason, knowledge of the closeness and combustibility of structures in a built-up area is also required in order to estimate the probability of the growth and spread of large-scale fires.

Experience has shown that, weather and terrain being the same, the lower the building density[3] of an area, the smaller will be the probability of fires spreading to other structures. An approximate relationship between probability of fire spread and building density is presented in figure 4-8.[2] A simplified analysis of this curve's significance is given in table 4-I.[2]

In addition to building density, the actual sizes of the spaces or fire gaps between buildings exert a strong influence upon the chances of fire spread. Figure 4-9[2,4] gives a rough plot of how the probability of fire

1. Refer to Table 3-IX for a list of flammable materials in this range.
2. Reference 38 in bibliography.
3. Building density equals the ratio of roof area to total ground area in a particular region.
4. Reference 1 in bibliography.

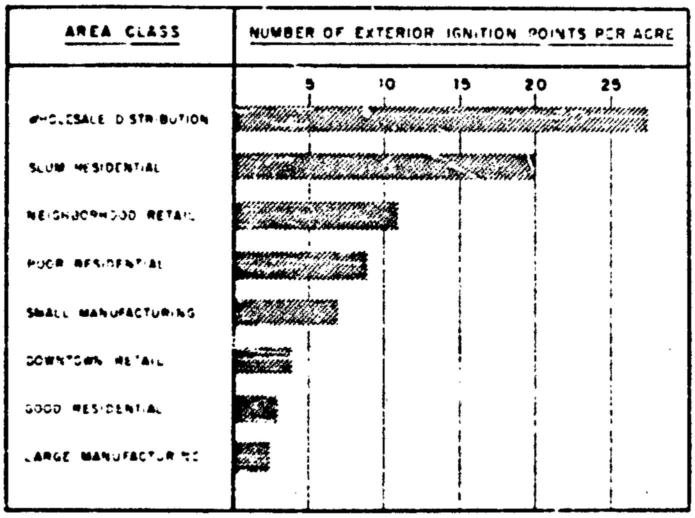

Figure 4-7. Frequency of Exterior Ignition Points for Various Areas in a City.

spread depends upon the average distance between buildings. From the steep portion of the curve it appears that the chances of fire spread assume an appreciable magnitude when fire gaps become less than 100 feet.

An understanding of the conditions of fire ignition and spread makes clear how several of the principles developed for fallout protection can greatly reduce the hazardous thermal effects of nuclear explosions. The following sections present these principles and supporting corollaries as well as various means for their implementation.

a. Reduction of Ignition Points. The incidence of potential ignition points may be decreased by the removal of kindling materials - at the same time making areas clear and accessible for decontamination. This includes:

(1) Hauling away <u>all</u> trash and avoiding its collection in open piles near buildings or combustible equipment and supplies.

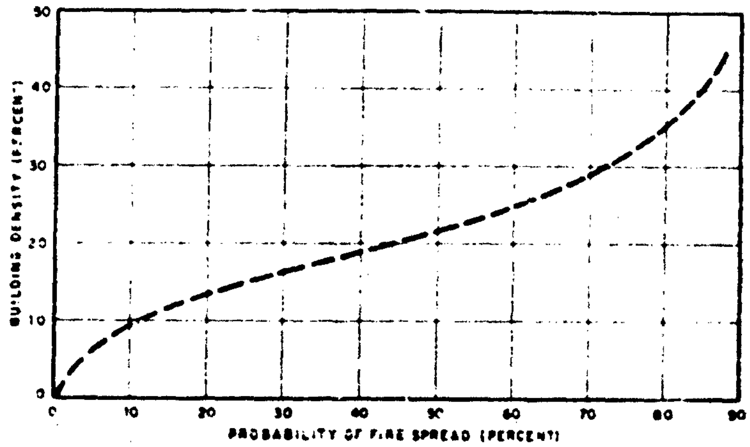

Figure 4-8. Probability of Fire Spread as a Function of Building Density.

Table 4-I. Significance Ranges of Building Density Versus Generalized Incendiary Effects.

Building Density (%)	Related Incendiary Effects
0 - 5	Fires do not usually spread beyond buildings in which they originate, since large open areas constitute major fire breaks.
6 - 20	Some fire spread may occur, but a mass fire is unlikely unless a large amount of kindling fuel is available.
over 20	Probability of mass fire is greatly increased provided density extends over an area of one square mile or more.

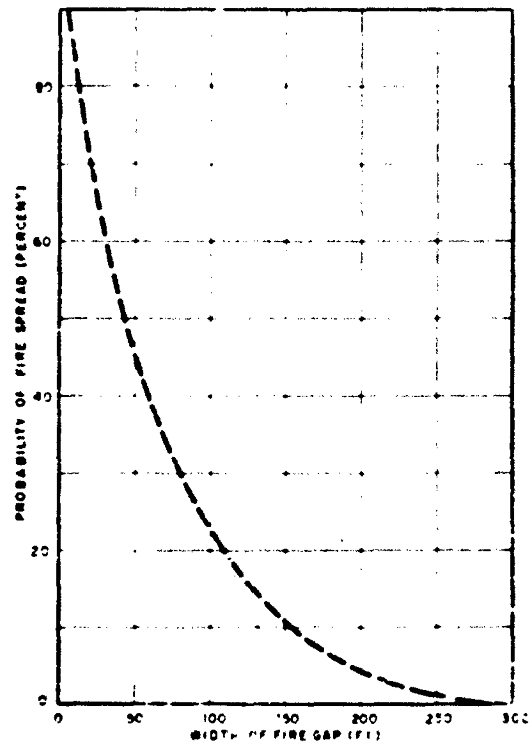

Figure 4-9. Probability of Fire Spread Versus Width of Fire Gap.

(2) Airing such ignitable items as rope well away from buildings having burnable exteriors.

(3) Eliminating all rotted portions from exposed wooden construction and striving for a high level of maintenance. The substitution of fire-resistant materials (concrete, brick and metal) for wood is advisable - particularly in new construction where the increased cost can be easily minimized (or justified from the standpoint of increased gamma shielding).

(4) Avoiding the use of dark-colored or otherwise combustible fabrics and interior materials that may be exposed at windows or other openings.

b. Shielding of Flammable Materials. A number of materials capable of starting or supporting fires cannot always be removed. Several measures may be taken to protect these materials from the thermal flash.

(1) Store all unremoved trash in closed metal or concrete containers. The buried types are ideal, since they cannot be tipped over by blast forces and their contents spilled. In addition, these flush mounted containers will not interfere with the recovery effort.

(2) Remove entry ports for thermal radiation. New construction can be made windowless, thus eliminating areas of zero shielding. Existing windows can be blanked off with fire-resistant sheets of transite and asbestos or dense gamma shields of metal or masonry. Other practical possibilities are the use of reflective coatings, venetian blinds, nonflammable curtains, shutters, and awnings over windows. Table 4-II[1] indicates the effectiveness of some window coverings in reducing entry of thermal radiation to building interiors.

Table 4-II. Reduction of Interior Thermal Radiation by Window Coverings

Material	Percent Reduction
Window glass	0
Aluminum shade (including screen)	70
Aluminum venetian blind (slats closed)	98
Aluminum venetian blind (slats at 45°)	30
Aluminum insect screen, 24 x 24 and 20 x 20 meshes	50
Aluminum insect screen, 14 x 18 mesh	35
Coating on glass - Bon Ami	50
Whiting	90
Opaque paint	35

1. Reference 38 in bibliography.

(3) Use special coating such as fire-retardant (intumescent) paint and thermo-shielding[1] (smoking) paint which prevent excessive temperature rises and, hence, the outbreak of fire. Regular paint will have some value if it is light enough in color to be reflective. All coatings should meet the requirements expected of radiologically protective coatings.

(4) Take advantage of hills and adjacent structures to provide shielding from thermal (and direct gamma) radiations. This applies to people as well as the location of buildings.

(5) Screen flammable structures or positions of structures by means of smoke screens or even a washdown system; use of these assumes sufficient warning prior to attack.

c. Improved Fire-Fighting Capability. In spite of the observance of the foregoing principles a certain number of ignition points will either go unnoticed or must be tolerated. It is, therefore, necessary to plan for the early extinguishment of any fires that could result before they reach serious proportions. Such planning must obviously include the services of a modern, well-equipped fire department. Not so obvious is the fact that every able bodied person at an installation can, if properly trained and equipped, contribute heavily by snuffing out incipient fires,[2] thus freeing the professional crews to concentrate on the larger blazes. This action can usually be completed before the arrival of fallout.

The success of both this "first aid" and the conventional type of fire fighting is largely dependent upon the ready availability of water. For this reason, and because of the critical role of water in recovery operations, certain measures would increase the reliability of the all-important water supply system.

(1) To relieve the strain on the principal water supply or because of its possible loss, auxiliary reservoirs are desirable. Other sources such as swimming pools and nearby lakes, rivers, canals, etc., should be explored.

(2) A network of independent water systems which can supplement each other are advisable for large complexes. Important areas should be fed by two separate systems from two directions.

1. Tests conducted at NRDL (see Reference 10) indicate that a sebacic acid ingredient could, by its interposition of a self-generating smoke screen between the substrate and the radiation, lower the temperature of Navy gray paint by 7 to 18 percent. This depends upon the irradiance level (5 to 22 calories per square centimeter per second) and the simulated weapon yield (20 kilotons to 10 megatons).
2. A plentiful distribution of fire extinguishers and buckets of water or sand would serve well in this phase.

(3) Sufficient outlets and valving must be provided to insure full coverage and flexibility. At least one hydrant should be located near each street intersection but clear of the curb. Capacity and frequency of hydrants will depend upon distance between intersections, building density and value or importance of property.

d. Prevention of Fire Spread by Dispersal.[1] The spread of fires over an installation may be further inhibited by adjusting the spatial arrangement or distribution of buildings, i.e., extending the principal of orientation and location. This is implied by the building density curve in figure 4-8. From the interpretation given in table 4-II it appears wise to maintain a density as far below 20 percent as is commensurate with the function of the installation in question. Achieving such a condition requires the enactment of one or more forms of dispersal.

Creation of fire-breaks by separating individual buildings represents the lowest level of dispersal. As is indicated by figure 4-9, large fire gaps are not usually practical, however effective they may be, against ordinary fires. Parapeted fire walls and moderate fire gaps which will accomodate firefighting and radiological recovery equipment represent a compromise solution.

A higher level of dispersal involves the segregation and isolation of building groups within an installation according to function and construction. Hospital, administration, and school areas should be kept separate from shop and storage areas. Ideally, all temporary structures should be replaced by structures that offer protection against the threat of fire and fallout. At the same time new structures must be located (upwind if possible) from old vulnerable buildings. Functional areas such as parade grounds, parking areas, recreation fields, furnish natural fire-breaks for achieving the desired degree of isolation. A fire gap approximately 250 feet wide (see figure 4-9) will insure almost complete containment of a fire in a given area. These breaks should occur in intervals of not more than 1000 feet. This more open form of dispersal will permit an aerodynamic orientation of buildings with respect to the prevailing winds (and each other) so as to reduce the collection of fallout (see Section 4.3.1).

Isolation of an entire military base from any combustible surroundings constitutes dispersal in its broadest sense. By bordering its perimeter with freeways, marshalling yards, waterways, golf courses, etc., an installation can immunize itself from the fire susceptibility of outlying regions. Such extreme dispersal, however, will offer little or no advantage radiologically.

4-07. PROTECTION BENEFITS AGAINST BLAST. Of the basic principles given thus far only shielding and orientation and location are applicable to blast-protective construction. When properly reinforced, shielding may

1. Reference 11 in bibliography.

lend a modicum of blast-resistance to a particular structure. Maximum blast protection can be procured only through specially designed construction such as underground shelters.

The degree of blast protection available in existing above-ground structures ranges from the strongest, represented by heavily framed steel and reinforced-concrete buildings, to the practically nonresistant, shed type structures having light frames and long unsupported spans. Selecting the design requires some knowledge of the expected dynamic loading to which it will be subjected. The blast forces and their effects are a function of both the variation of the shock wave with time and of the dimensions and strength of the structure itself (see section 3-02). These in turn depend upon the location of the facility relative to the probable point of detonation, the weapon yield, and its height of burst. Postulating these conditions permits structural analysis to determine the properties necessary for a given installation to withstand the predicted explosive forces.

Without going into further detail on the complex subject of structural resistance, four design criteria are listed below for minimizing blast as well as the other weapon effects.

1. Windowless buildings of reinforced concrete provide the greatest blast protection at a cost little above that of existing construction. Buildings whose exterior concrete membranes are pierced by small windows are next in order of blast resistance.

2. Cellular construction utilizing a system of high-strength (shear) walls is a practical and economical way of achieving the same degree of protection referred to in (1). Even when limited to stair wells, elevator shafts and utility tunnels, shear walls provide a low cost structural core of great strength. Existing buildings may also be substantially bolstered by the replacement of interior walls and partitions with shear walls, particularly when laid out on a cellular scheme.

3. The use of brittle materials and components such as glass and unreinforced concrete or masonry should be avoided. These fail under relatively low blast pressures and form dangerous missiles By the same token, fixtures and ornamental plaster or other interior treatment that might be shocked loose should be eliminated if possible. Where windows are indispensable their area should be minimized. Protective screens of 1/4 inch hardware cloth are recommended inside of windows to stop flying fragments.[1] Tempered glass or plastic 1/4-inch thick is approximately 5 times stronger than safety glass or wired glass of equivalent thickness.

4. Side-on blast pressures can be reduced by orienting buildings so as to present a minimum of frontal area to the approaching shock wave. Of

1. Reference 12 in bibliography.

course, this presupposes that a reasonable estimate can be made of the anticipated explosion center relative to the building site location. Further reduction in blast damage is possible by taking advantage of the shielding offered by hills and by stronger and larger structures. Where space permits, buildings might even be separated so as to reduce the likelihood of damage from debris originating in weaker structures that may ultimately be destroyed.

4-08. SUMMARY. A number of principles have been presented for the protection of facilities and their personnel from fallout and its effects. In certain instances, these principles also have been shown to offer protection against blast and thermal effects. These, however, are considered to be fringe benefits. The guiding purpose behind the foregoing principles is fallout protection.

Slanting construction to improve fallout protection represents a departure from the traditional concept of protective construction. It is, therefore, important that the principles involved be firmly established before their application in the design of construction is discussed. For this reason, the protective principles recommended in this section, together with related corollaries, are reviewed below.

1. Design for more massive roofs, floors, walls, and partitions.

2. Form a distant envelope about the uncontaminated interior.

3. Minimize projections and voids.

4. Orient structures with respect to the prevailing winds.

5. Avoid unnecessary horizontal surfaces.

6. Provide prominent slopes to nonvertical surfaces.

7. Use smooth, hard, water-repellent, and chemically inert materials.

8. Reduce size and number of joints and seams connecting surface materials.

9. Furnish high-velocity drainage.

10. Allow for exterior access to building roofs.

11. Widen spaces between buildings and keep them clear of obstructions such as service poles, fire hydrants and lamp posts.

12. Substitute ramps for stairs to accommodate rolling equipment.

13. Avoid deep-rooted vegetation, shrubs or trees.

14. Incorporate auxilliary water sources with main supply system.

SECTION V - APPLICATION OF PROTECTIVE PRINCIPLES IN THE DESIGN OF NEW BUILDINGS

Many planned structures can be made to furnish fallout protection and increased resistance to the destructive effects of a nuclear attack, by the timely application of protective construction principles described in Section IV. To take full advantage of these principles and minimize any additional cost, they should be introduced early in the design or planning stages of all new construction. Principles which may be used to improve those structural design features influencing the degree of fallout protection are evaluated in this section in terms of relative cost and effectiveness.

5-01. IMPROVEMENT OF SHELTER EFFECTIVENESS. To improve the sheltering effectiveness inherent in buildings, and thereby satisfy the first objective of greater fallout protection, it is necessary for the designer to consider the principles of shielding and distance protection together (see section 4-02). The factors upon which these two principles of sheltering effectiveness depend are:

1. Size of buildings as given by floor area and/or volume.

2. Geometry of buildings, i.e., the length-to-width ratio, L/W, and the number of stories.

3. Thickness and density of walls, roof, floors, and other elements - expressed as the mass thickness in pounds per square foot.

4. Window space and other wall openings offering zero shielding

5. Location of point of maximum protection within a building with respect to its perimeter and floor level.

6. Roughness of surrounding terrain.

The complex interrelationships among those factors makes generalization difficult. Consequently, this discussion is limited to considering the variability in shelter effectiveness afforded by four simplified building types. These are defined in table 5-I in terms of building materials and the mass thickness of the structural components.

In order to determine the relative importance of these factors, certain target conditions in a fallout situation have been assumed. The fallout material is uniformly spread on roofs and ground areas, and wall and other vertical surfaces are uncontaminated. While not altogether realistic, these assumptions are acceptable for making comparisons. Because of the

Table 5-I. Four Simplified Types of Construction

Type	Materials	Component	Mass Thickness (lb/ft^2)
Light	Wood and sheet metal	Walls	12.5
		Floors	12.5
		Roof	12.5
Medium	Concrete and steel, masonry, and dense materials.	Walls	75
		Floors	75
		Roof	50
Heavy	Concrete and steel, masonry, and dense materials	Walls	150
		Floors	150
		Roof	100
Mixed*	Wood, sheet metal, concrete and steel, and dense materials	Walls	75
		Roof	12.5

*Representative of much recent one-story construction where tilt up slabs of 6-inch concrete are used for walls, and roofs are light by comparison (equivalent to 1 inch of concrete).

advantage to radiological recovery operations, all buildings are situated in paved surroundings. As a further simplification, buildings are windowless and have no partitioning walls or divisions, unless otherwise noted.

<u>a</u>. <u>Point of Greatest Protection</u>. It can be demonstrated that either the <u>center</u> or the <u>corners</u> of a given floor are the points of maximum or minimum protection for most conventional structures. Which of these locations provides the most shelter depends upon the relative contribution of roof and ground contamination as well as the aforementioned factors. Thus, it is necessary to constantly check the shelter effectiveness at both center and corner locations as the design of protective construction develops.

<u>b</u>. <u>Roof and Ground Contributions</u>. Results from weapon tests[1] involving surface and subsurface detonations indicate that the principal sources of radiation within a structure are the roof and ground contamination. Figure 5-1 depicts the relative contribution of the two

1. Reference 6 in bibliography.

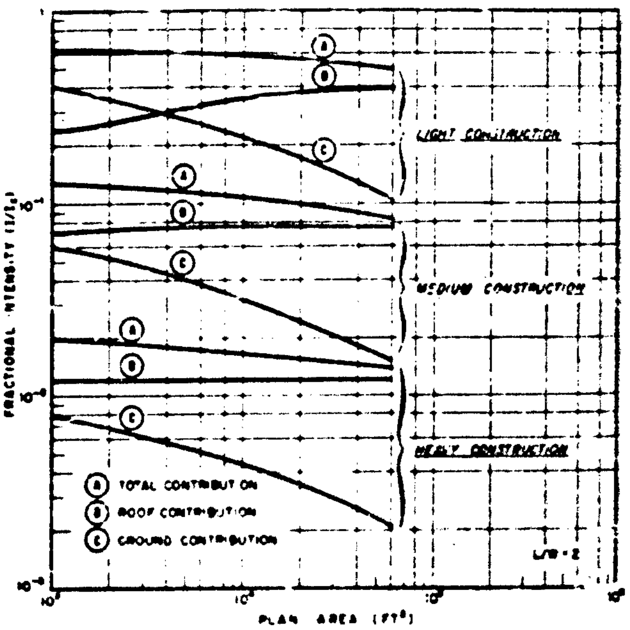

Figure 5-1. Relative Contribution From Roof and Ground Contamination to Fractional Intensity at the Center of Single-Story Buildings Having a Length-to-Width Ratio (L/W) of 2.

sources to the fractional intensity[1] at the center of one-story buildings. The curves for light-weight construction show the dominant radiation source to shift from the ground for smaller buildings to the roof for larger buildings (> 4000 square feet). Roofs are shown to be consistently the main contributors of radiation for medium or heavy-construction regardless of area.

1. As applied to structures, the fractional intensity is the ratio of the dose rate, I, inside to the unaltered dose rate, I_o, outside. Therefore, it is a direct measure of the shelter effectiveness.

Table 5-II. Relative Contribution From Roof and Ground Contamination to Fractional Intensities at the Corners of Single-Story Buildings

Weight of Construction	Fractional Intensity (I/Ix)* Roof	Ground	Total
Light	0.095	0.405	0.50
Medium	0.019	0.022	0.041
Heavy	0.0030	0.0032	0.0062

*These corner protection values apply to floor areas of 1000 to 40,000 ft^2.

However, at building corners, the fractional intensities are essentially constant with respect to floor area; the corresponding values (relative and total) are presented in table 5-II.

These protection values reveal that, for building corners fallout on the surrounding ground area is the major source of radiation. As the construction weight increases, the roof contribution is seen to approach and nearly equal that from the ground.

A comparison of the total fractional intensities in figure 5-1 and table 5-II shows that location within a light-weight single-story building is of small consequence. For medium- and heavy-weight construction, however, corner locations provide maximum protection.

In the case of multistoried buildings, it can be shown that, except for top floors, the ground contributions exceeds that of the roofs in both the center and corner locations. The roof contribution rapidly diminishes with increased weight of construction until only the ground sources are worth any concern.

c. Effects of Building Size, Shape, and Massiveness. The relative dimensions of a structure may have some influence on its shelter effectiveness where the length-to-width ratio (L/W) is greater than 4. The most frequently occurring L/W ratios, however, lie between 1 and 4. Within this interval the effect is practically negligible, compared to other construction factors. There is an exception in the case of mixed construction, which will be treated in a later section. To simplify the examples and discussion to follow, an L/W ratio of 2 is assumed.

Figures 5-2 and 5-3 show the improvement in center and corner protection, respectively, as a function of three controlling building features.

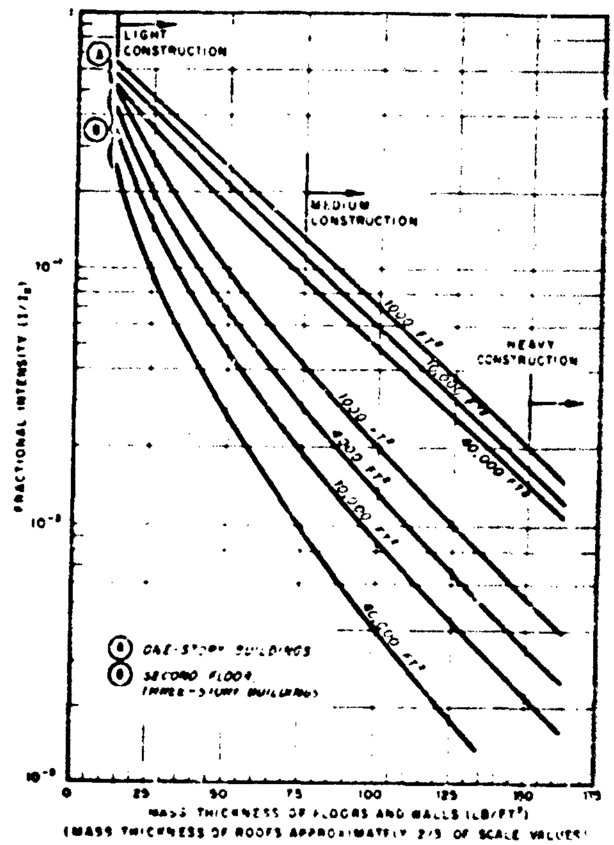

Figure 5-2. Center Protection Versus Weight of Construction

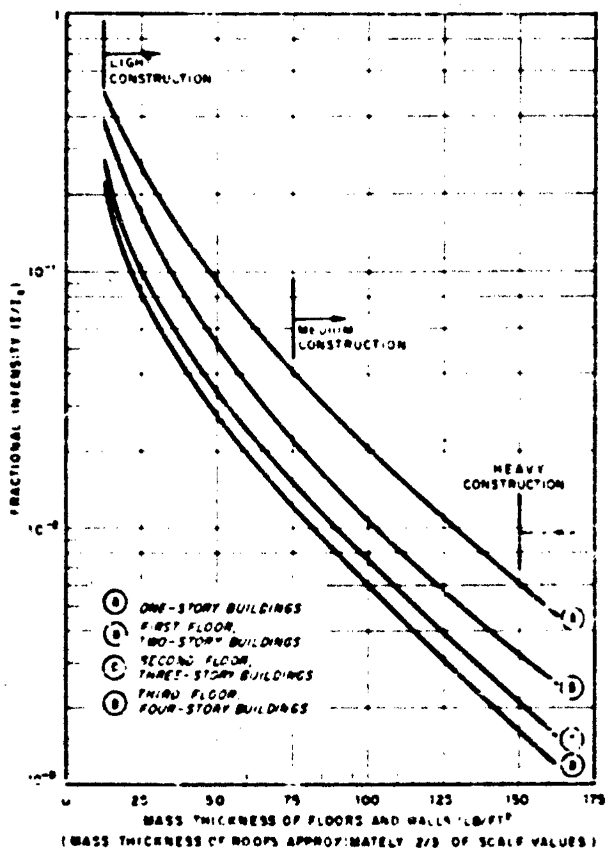

Figure 5-3. Corner Protection Versus Weight of Construction

They are in order of decreasing importance: 1) weight of construction, as denoted by the mass thickness of building components; 2) number of stories; and 3) building plan area.

(1) Weight of construction. The rapid gain in shelter effectiveness with modest increases in weight of construction is graphically demonstrated by the pronounced negative slope which characterizes all the curves in the above figures. In figure 5-2, those belonging to Plot B exhibit the steepest slopes, thereby indicating the center protective benefits of increased mass thickness to be considerably greater for multistoried buildings, especially those having larger plan areas. A parallel but less obvious relationship is discernible from the curves of figure 5-3 for corner protection values. Here the increase in slope with additional floors is most noticeable in the interval between light- and medium-weight construction.

(2) Number of stories. Aside from enhancing the advantage of heavier construction, the addition of extra floors offers a secondary but independent means for significantly improving the sheltering capabilities of structures. The effectiveness of such additions is apparent from the difference in values between the single story curves and their multistory counterparts. Only the floor providing maximum protection is shown. Except for light-weight construction the greatest protection exists one floor removed from the top story. It must be understood, however, that should the mass thickness of roofs be reduced to some value less than 2/3 that found in the walls and floors, maximum protection must necessarily shift to a lower floor.

Figure 5-3 reveals that the difference in values between adjacent curves, and hence the gain in corner protection, grows progressively smaller with each additional story. The same is true for center protection, though not represented in figure 5-2. In view of this apparent condition of diminishing returns, more than six or seven stories cannot be justified.

(3) Building plan area. As was mentioned earlier and is borne out in figure 5-3, plan area has no appreciable effect on corner protection. For single-story buildings, figure 5-2 shows very little improvement in center protection even for large increases in plan area. Only in multistory construction is the influence of building plan area truly significant. Even so, the protection possible through heavier construction or extra floors is far greater by comparison.

d. Advantages of Heavy, Multistoried Construction. From the foregoing section, one can appreciate the difficulty of analyzing each of the three building features which most improve sheltering, since a change in one is immediately reflected in the other two. A more realistic approach is represented in figure 5-4 where fractional intensities are

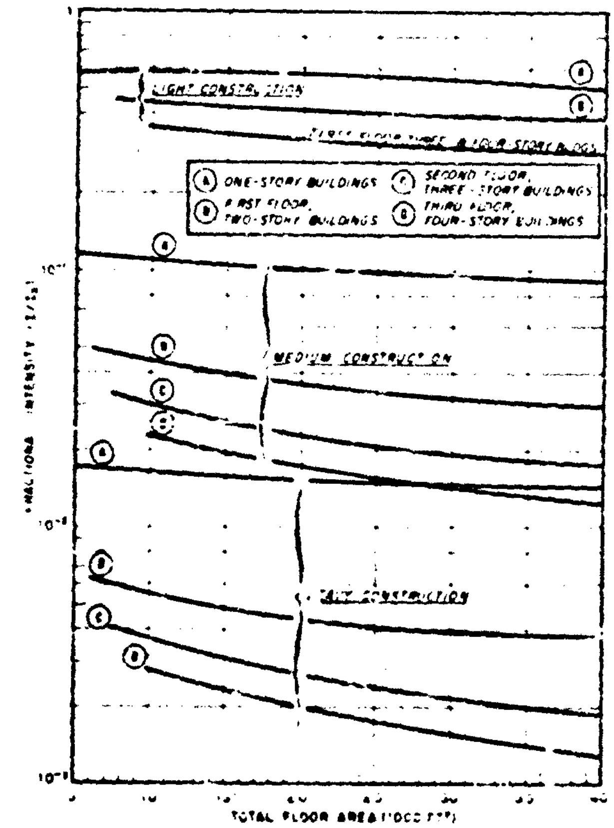

Figure [illegible]. Floor Levels of Maximum Center Protection for Buildings Having Same Total Floor Area or Volume

BEST AVAILABLE COPY

given as a function of total floor area[1] (summation of area on all floors). This approach is more significant inasmuch as total area or volume is usually fixed early in the design stage. The curves clearly demonstrate the center protection to be gained with heavier weight, multistoried construction. The value of increased total area is seen to be comparatively small.

Table 5-III. Comparison of Maximum Center and Corner Protection in Buildings of One to Four Stories

Type of Construction	No. of Stories	Story	Fractional Intensity (I/Ix) Center*	Corner**
Light Weight	1	-	0.50	-
	2	1st	0.38	-
	3	1st	0.28	-
	4	1st	0.28	-
	1	-	-	0.50
	2	1st	-	0.35
	3	2nd	-	0.28
	4	3rd	-	0.25
Medium Weight	1	-	0.090	0.042
	2	1st	0.030	0.023
	3	2nd	0.018	0.015
	4	3rd	0.012	0.012
Heavy Weight	1	-	0.014	0.0060
	2	1st	0.0038	0.0034
	3	2nd	0.0019	0.0020
	4	3rd	0.0013	0.0016

* Center values for buildings having a total floor area of 40,000 ft^2.
**Corner values apply to total floor areas of 4000 through 40,000 ft^2 and beyond.

Table 5-III lists the maximum protection values according to construction type, number of stories and floor level. Except for single story buildings of medium or heavy construction, there is little if any protective advantage of corners over center locations. However, as explained in the footnote to table 5-III, the center protection values are for total floor areas of 40,000 square feet. For lesser areas, corners would consistently be the safest position regardless of mass thickness.

1. Building volume (cubic footage) could have been used just as well. The same curve would have resulted.

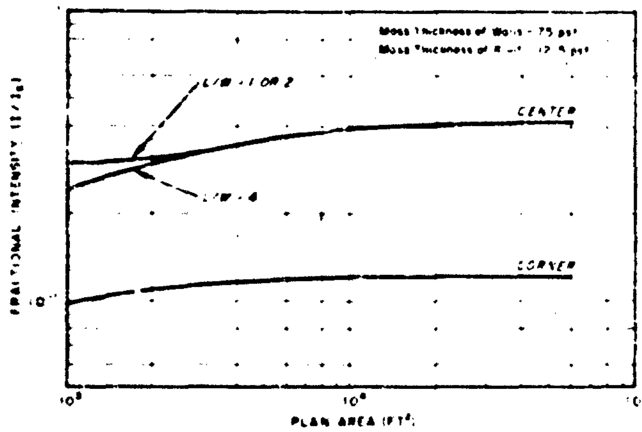

Figure 5-5. Protection in Single-Story Buildings of Mixed Construction.

e. Mixed Construction. Because of the popularity of mixed construction (see table 5-I) and because of the associated sheltering problems, it deserves special consideration. The protection afforded by such structures is shown in the curves of figure 5-5. A comparison of the center protection curve with the total contribution curves in figure 5-1 points up some rather interesting sheltering differences between construction types. As expected, the center values for mixed construction fall midway between those for light-weight and medium-weight construction. However, unlike the latter two types, center protection in mixed construction is seen to gradually decrease with enlarging floor area. It should also be noted that for plan areas under 4000 square feet, the L/W ratio becomes controlling. Thus, buildings which are of narrow width and small area provide more center protection than wider and more expansive structures.

Corner protection, as indicated by the relative position of the curves in figure 5-5, is considerably greater than at the center. Although not sensitive to L/W ratios, corner protection also gradually decreases as floor area approaches 10,000 square feet. Beyond this point corner values are essentially constant.

The reason for the unique shelter problems raised by mixed structures is the heavy contribution of roof contamination. Ground contributions are kept small, in comparison, by the wall mass thickness ([illegible] pounds per square foot). One obvious solution, then, is to increase roof mass thickness. The feasibility of another solution, employing a roof washdown system with such construction, is discussed in section 5-64.

f. Protection Afforded by Basements. Generally, the greatest protection available in any building is in the basement. Figure 5-6 shows the basement shelter effectiveness as a function of the mass thickness in the ground floor for various types of buildings. As in aboveground shelters, basement protection (center or corner) is greatest in multistoried, and/or heavily constructed buildings. The effect of increased area is restricted to improving center protection of a two-story building, as indicated in Plot B. Similar plots for three- and four-story structures give no justification for exceeding two stories. Corner protection, as is represented in Plot C, is superior to that at basement centers by extremely large factors; depending upon the weight of construction and whether there are one or more stories.

A comparison of the above curves with those of figures 5-2 and 5-3 reveals the importance of basement shelters. Even where the mass thickness of the floor directly above the basement is quite small, as in lightweight construction, basements offer considerably more protection than do the ground or upper stories. This protection can be increased by adding to the mass thickness of the ground floor, without changing the aboveground construction whatsoever.

g. Influence of Openings. All preceding examples and discussion have been concerned with windowless buildings. The use of windows and lightly constructed doors reduces sheltering effectiveness considerably. This is evident from figures 5-7 and 5-8 where the effect of window space equal to 2/3 and 1/3 of the total wall area is compared with that of windowless design. The influence of wall openings on center protection in light construction is practically negligible (see Plot A, figure 5-7). For medium weight construction the effect is quite significant (see Plot B). The curves in figure 5-8 represent this effect as being most drastic in the case of heavy-weight construction.

Table 5-IV contains the corner protection values and compares them with center values for buildings of 40,000 square feet. It is evident from these entries that even with fewer than 1/3 wall openings the protective advantage generally exhibited by corner locations in windowless buildings is all but last. Because of the resultant reduction in wall shielding effectiveness and the increased chances for interior contamination, windows or other openings should be eliminated.

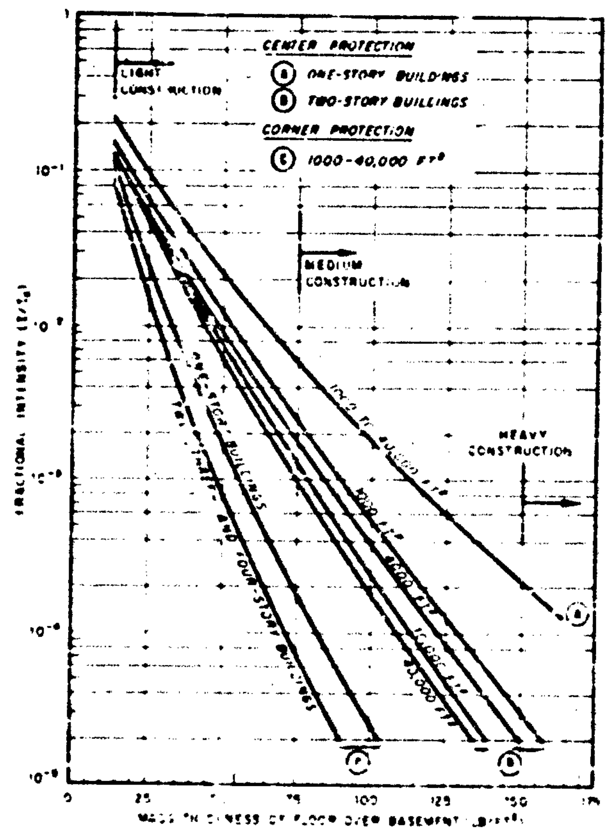

Figure 5-6. Protection in Basements Versus Weight of Construction.

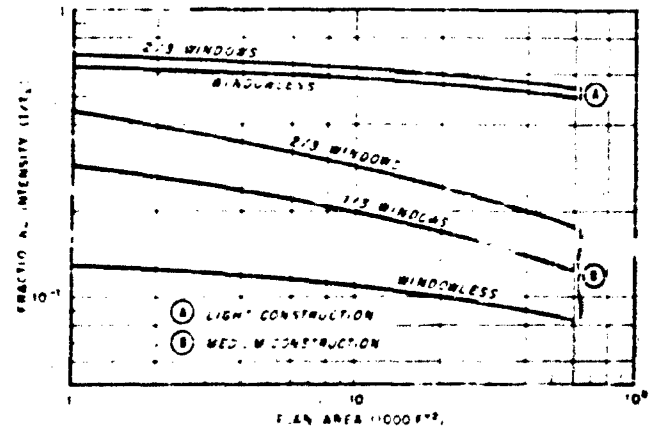

Figure 5-7. Loss of Center Protection Due to Windows in Single-Story Buildings.

Table 5-IV. Comparison of the Effects of Window Space on Center and Corner Protection of One Story Buildings

Type of Construction	Window Fraction	Fractional Intensity (I/Ix) Center*	Corner**
Light weight	0	0.52	0.50
	1/3	0.53	0.64
	2/3	0.55	0.77
Medium weight	0	0.09	0.041
	1/3	0.1[illegible]	0.30
	2/3	0.20	0.57
Heavy weight	0	0.015	0.006
	1/3	0.07	0.27
	2/3	0.13	0.53

* Center values for buildings having a floor area of 40,000 ft^2.
**Corner values apply to floor areas of 1000 to 40,000 ft^2.

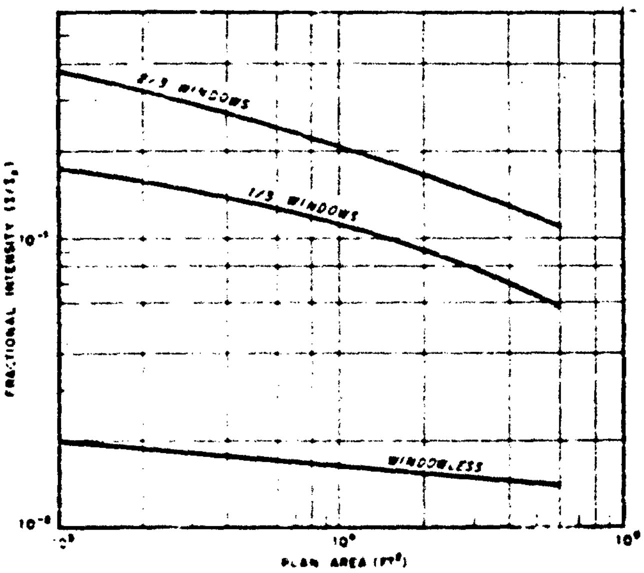

Figure 5-8. Loss of Center Protection Due to Windows in Heavily Constructed Single-Story Buildings.

b. Shielding Effectiveness of Structural Material and Components. In the preceding examples and discussion the advantage of heavier construction has been emphasized. Thus denser materials should be introduced into protective construction whenever costs and other design considerations permit. A representative cross-section of the many materials commonly available is shown in table 5-V.[1] Nominal thickness (inches) and mass thickness (pounds per square foot) of each material are also listed. This latter term, although not equal to density, is proportional to it and, therefore, provides a means of gaging the shielding potential of one material relative to another.

In the course of any building design, the shielding value of the various components must be evaluated. Since the components are fabricated from base materials, the information in table 5-V may be combined to obtain mass thicknesses of roofs, walls, floors, ceilings, etc. Some

1. Reference 13 in bibliography.

Table 5-V. Shielding Potential (Mass Thickness) of Building Materials.*

Material	Component	Nominal Thickness (inches)	Mass Thickness (lb/ft^2)
Adobe	wall	12	116
Asbestos board	wall	3/16	1.7
Asbestos, corrugated	roof, wall	-	4
Asbestos shingles	roof, wall	5/32	1.8
Asphalt, 3 ply, ready	roof	-	1
Asphalt, 4 ply & gravel	roof	-	5.5
Asphalt, 5 ply & gravel	roof	-	5.2
Asphalt shingles	roof	-	2.3
Book tile	roof	2	12
	roof	3	20
Clay brick	wall	4	38 - 40
	wall	8	69 - 89
	wall	12-1/2	100 -130
	wall	17	134 -174
Clay tile shingles, flat	roof	-	10 - 20
Clay tile shingles, spanish	roof	-	8.5- 10
Clay tile, structural	wall	4	16
	wall	8	42
	wall	12	58
Clay tile, interior	wall	4	18
	wall	6	28
	wall	8	34
	wall	10	40

Continued

*Table is from Reference 13 in bibliography.

Table 5-V. Shielding Potential (Mass Thickness) of Building Materials. (Continued)

Material	Component	Nominal Thickness (inches)	Mass Thickness (lb/ft²)
Clay tile, facing	wall	2	15
	wall	4	25
	wall	6	38
Concrete, poured:			
<u>low density</u>			
Vermiculite	wall, roof, floor	per inch	2 - 4
perlite	wall, roof, floor	per inch	3.5- 5.5
diatomite	wall, roof, floor	per inch	4.5- 6
pumice	wall, roof, floor	per inch	5 - 7.5
foam slag	wall, roof, floor	per inch	7.5- 8.5
haydite	wall, roof, floor	per inch	8.5-10
cinders	wall, roof, floor	per inch	9 - 9.5
crushed slag	wall, roof, floor	per inch	10 -11
<u>conventional</u>			
crushed stone	wall, roof, floor	per inch	12
gravel-sand	wall, roof, floor	per inch	12 -12.5
reinforced	wall, roof, floor	per inch	12.5
<u>high density</u>			
limonite	wall, roof, floor	per inch	15 -16
hydrous iron ore	wall, roof, floor	per inch	18
barite	wall, roof, floor	per inch	18 -19
magnetite	wall, roof, floor	per inch	19 -20
barite-iron shot	wall, roof, floor	per inch	22
ferrophosphorus-barite	wall, roof, floor	per inch	22
iron-limonite	wall, roof, floor	per inch	22
ferrophosphorus	wall, roof, floor	per inch	25
iron-magnetite	wall, roof, floor	per inch	25 -29
iron slugs - iron shot	wall, roof, floor	per inch	31 -34

Continued

Table 5-V. Shielding Potential (Mass Thickness) of Building Materials. (Continued)

Material	Component	Nominal Thickness (inches)	Mass Thickness (lb/ft2)
Concrete block, hollow:			
light aggregate (cinder or slag)	wall, partition	4	20
	wall, partition	6	28
	wall, partition	8	38
	wall, partition	12	55
heavy aggregate (stone)	wall, partition	4	26 -34
	wall, partition	6	38 -46
	wall, partition	8	50 -60
	wall, partition	12	75 -95
Concrete brick:			
Light aggregate (cinder or slag)	wall	4	32
	wall	8	68
	wall	12-1/2	98
heavy aggregate (stone)	wall	4	46
	wall	8	90
	wall	12-1/2	130
Concrete shingles	roof	-	16
Fiber board	wall	1/2	0.8
Fiber sheathing	wall	1/2	0.9
Glass block masonry	wall	4	18
Gypsum block	wall	2	8 -11
	wall	3	10.5
	wall	4	10 -15
	wall	6	19.5
Gypsum board	wall, ceiling	1/2	2.1
Gypsum plank	roof	2	12

Continued

Table 5-V. Shielding Potential (Mass Thickness) of Building Materials. (Continued)

Material	Component	Nominal Thickness (inches)	Mass Thickness (lb/ft^2)
Marble facing	wall	2	26
Plaster, directly applied	wall, ceiling	3/4	5
Plaster on fiber lath	wall, ceiling	1/2	5
Plaster on gypsum lath	wall, ceiling	1/2	5
Plaster on metal lath	wall, ceiling	3/4	6
Plaster on wood lath	wall, ceiling	3/4	5
Plaster, solid	wall	2	20
	wall	4	30
Plaster, hollow	wall	4	22
Plywood, finish	wall	5/16	1
	ceiling	1/2	1.5
Plywood, sheathing	wall, roof	3/8	1.1
Slate	roof	3/16	7.3
	roof	1/4	10
Split furring tile	wall	1-1/2	8
	wall	2	12
Steel, corrugated	roof, wall	20 ga.	2
Steel panel	wall, roof	18 ga.	3.3
Steel partitions, insulated	wall	-	6
Stone	wall	12	130
Stone, cast, facing	wall	2	24

Continued

Table 5-V. Shielding Potential (Mass Thickness) of Building Materials. (Continued)

Material	Component	Nominal Thickness (inches)	Mass Thickness (lb/ft²)
Stucco, metal lath	wall	3/4	9
Stucco, wood lath	wall	3/4	8
Terra Cotta facing	wall	1	5.4
Terrazzo	floor	1	12
Wood block	floor	3	10
Wood finish	floor	25/32	2.5
Wood sheathing	floor, roof	3/4	2.5
Wood shingles	roof	-	2.5
Wood shingles, 6-1/2" to weather	wall	-	1.1
Wood siding, 3" bevel	wall	-	1.5
Wood siding, 6" drop	wall		2.5
Wood studs, exposed	wall	2 x 4	1.6

mass thicknesses of a few typical structural components are given in table 5-VI. By using mass thickness values in conjunction with figure 5-9, the designer may quickly estimate the expected shielding effectiveness of any material or building member. The use of mass thickness is especially convenient, since the weights of materials and components are generally given in terms of square feet in the various builder's handbooks.

It should be understood that the curve of figure 5-9 represents the case of simple shielding only. That is, it provides a ready and suitable means for approximating the degree of improvement in the shielding to be gained by the substitution of materials or components. The curve incorporates no adjustments for such involved phenomenon as the multiple scattering of the penetrating radiation. This and other aspects are important in the gross design considerations and are reflected in the protection values given in the preceding curves and tables.

Of all the entries in tables 5-V and 5-VI, concrete and its components offer the greatest shielding potential. Because of this inherent property and its wide acceptance in present day building, concrete is an excellent material for protective construction. As indicated in table 5-V a wide range of mass thicknesses are available depending upon the type of aggregate used.

Conventional concrete, consisting primarily of sand and gravel, will probably be satisfactory in most instances. Where it is imperative to reduce the bulk and massiveness of structural components, the denser (and more expensive) concretes may be employed. Tables 5-VII[1] and 5-VIII[1] present cost data and physical properties of a number of such concretes and their aggregates. In general, conventional concrete weighing about 150 pounds per cubic foot costs $50 to $125 per yard, installed, while the cost of high density concrete may run $200 to $1000 per yard.

Although the unit price of these special concretes is higher, their proper use may actually reduce the overall building cost and still provide greater shielding. Table 5-VII indicates that large savings may be realized by employing only the natural heavy aggregates shown above the dashed lines. The denser mixes, occurring below the dashed lines and containing iron and ferrophosphorus aggregates, are 3 to 7 times more costly. This increase in relative cost of materials is out of all proportion to the corresponding increase in density, in shielding, insofar as protective construction is concerned.

i. Summary. As a result of the above findings, an ideal above-ground structure with built-in protection might be pictured as a heavily constructed, multistoried, windowless building having an extensive

1. Reference 14 in bibliography.

Table 5-VI. Shielding Potential (Mass Thickness) of Some Typical Structural Components.

Component	Description	Mass Thickness (lb/ft^2)
Walls, exterior*	Wood frame, asbestos siding	4- 6
	Wood frame, stucco	12- 14
	8" hollow concrete block, stucco	64- 69
	12" reinforced concrete, facing	156-176
	17" solid brick, facing	160-180
Walls, interior	Wood frame, wall board	4- 8
	4" clay tile, plaster 1 side	23**
	4" concrete block, plaster - 1 side	35**
Floors	Wood flooring supported by:	
	Wood joists	6
	14" open web steel joist, 2-1/2" conc. slab	60
	One way ribbed slab, 6" rib, 2" slab	47
	9" metal deck, 2" conc. slab	35
Roofs	Wood joist, composition shingles	3.5
	Wood joist, 4 ply, tar & gravel	6.5
	14" open web steel joist, 2-1/2 gypsum & standard built up roofing	36
Ceilings	Wood frame, Wall board	1- 3
	Wood frame, plaster	6.5
	Suspended metal lath & plaster	15

* For interior plaster finish add 5 (lb/ft^2).
**For 2 sides plastered add 5 (lb/ft^2).

Table 5-VII. Weight and Cost of Materials for 16 Types of High Density Concrete

Weight of Ingredients in lb/ft^3 of Final Mix				Weight of Mix (lb/ft^2)	Relative Cost of Materials per ft^3 of Conventional Mix
Coarse Aggregate	Fine Aggregate	Cement	Water		
Conventional Placement					
61 gravel	50 sand	31.3	11.5	154	1
76 L	62 L	31.3	15.4	135	6.2
100 HI	82 HI	24.9	12.0	219	4.2
105 B	86 B	19.3	11.6	222	6.1
110 M	86 M	24.3	11.5	232	4.4
70 F + 50 B	70 F + 35 B	23.7	12.8	262	15.5
100(#1320-S)	+ 49(#330-S) + 65 I	34.0	13.5	262	22.6
171 F	92 F	24.1	12.7	300	[illegible]
161 F	107 F	M.C.*	-	300	30.8
Prepacked Placement					
28 L + 122 M	29 L	22.7	12.5	215	5.5
108 B	29 B	19.3	10.5	227	5.6
130 M	37 M	17.5	9.7	244	5.1
60 L + 140 I	26 L	22.2	12.2	263	22.4
67 M + 160 I	42 M	19.8	10.5	300	23.8
270 I	44 M	20.6	11.3	346	36.8
Grouted Placement					
324 I	63 (#110-S)	16.8	5.9	416	50.8

*12.2 lb/ft^3 of MgO Powder and [illegible] lb/ft^3 of $MgCl_2$ Solution.

Legend: L - limonite, HI - hydrous iron ore, B - barite, M - magnetite, S - steel shot, F - ferrophosphorus, I - iron and steel scrap, punchings or sheared bars.

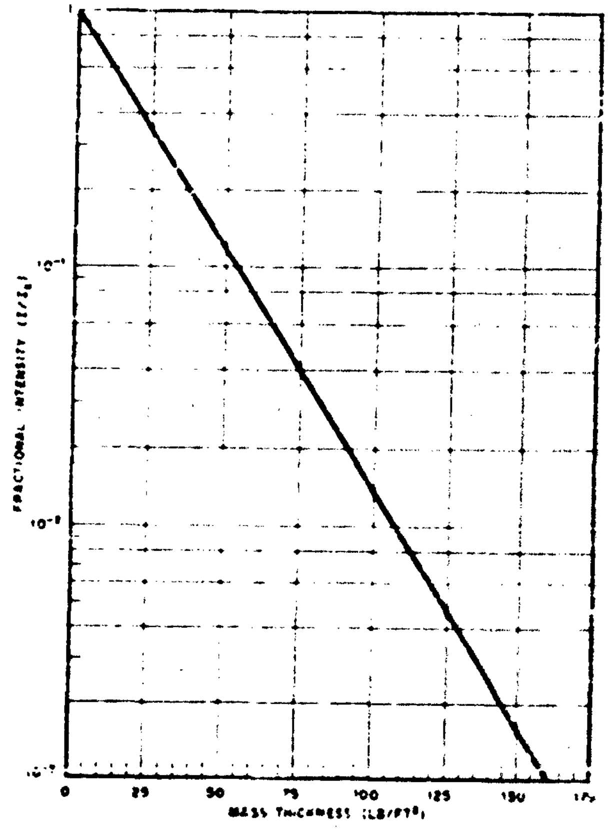

Figure 5-9. Effectiveness of Simple Shielding of Materials Against Fallout Radiation as a Function of Mass Thickness.

Table 5-[illegible] [illegible]

Heavy Aggregates	[illegible]	[illegible] Identification [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Limonite-Goethite	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Hematite	Nevada	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Magnetite	Montana	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Barite	Tennessee	9[illegible] % Ba[illegible]	4.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Barite	Nevada	[illegible] % Ba[illegible]	4.[illegible]	4.31	[illegible]	[illegible]	[illegible]	[illegible]
Ferrophosphorus	Tennessee and Missouri	[illegible]	6.30	6.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Steel Aggregate	Punchings	Sheared Bars	7.[illegible]	-	99		1.[illegible]	[illegible]
Steel Shot	Chilled	[illegible] standard	-	[illegible]	98	[illegible]	[illegible]	[illegible]

[illegible]
Values for processed aggregates include [illegible] per ton for freight [illegible].
**This ore is primarily magnetite, with some hematite [illegible] and limonite.

floor area. Because of space restrictions, functional requirements and construction costs, certain protective features must necessarily be weakened or even sacrificed in reaching a compromise solution. In fact, the site may be so situated with respect to potential target areas as to not justify a building which provides a high level of protection. Thus, in order to achieve a balanced design, it is necessary for the expected shelter effectiveness to be decided at the outset along with the rest of the preliminary specifications.

The information presented in the preceding sections covers a broad range of possible situations, and serves to emphasize the significant properties of the more important building features with respect to shelter effectiveness. With this kind of information it is possible at the preliminary sketch stage to quickly spot protective weaknesses in any candidate design. For instance, every attempt should be made to eliminate windows or other openings. The reduction in construction cost, building maintenance and heating and air conditioning requirements will more than cover the expense of additional lighting requirements.

Multistoried plans should replace those of one story structures, particularly when limited funds prevent the use of heavier construction. It [illegible] and conserve costs by increasing the [illegible] which comprise a given story. [illegible] floor is then designated as the emergency shelter for all the [illegible]

The advantages of including basements in building plans should not be overlooked. Not only [illegible] provide an area of maximum protection, but the valuable contribution they may make to the building's over-all function [illegible]

Where a high degree of shelter effectiveness is warranted, increased weight of construction may [illegible] the only solution. Even so, the resultant [illegible] should be supported by adjustments in floor area, number of stories, etc. [illegible] and sound engineering practice.

[illegible] the preliminary screening, its sheltering [illegible] to a more exact and detailed [illegible] to describe here, a well systematized [illegible] of Reference 1.

It [illegible] that the findings noted thus far involved only buildings whose interiors were [illegible] by walls and partitions. For this reason [illegible], in nearly all instances, were observed to furnish more protection than [illegible]. The existence of partitions, [illegible] advantage which has been [illegible]. [illegible] are included in Appendix [illegible] of

References for estimating the improved protection due to partitions, [illegible] walls, service tunnels, and the like. In the case of warehouses, shops, hangars and other industrial buildings which contain few or no interior walls, corners will still be the safest location. Exceptions may arise where roofs are 20 feet or higher and floor areas exceed [illegible],000 square feet, or where shielding is provided by equipment and stored material.

[illegible]. REDUCED COLLECTION AND RETENTION OF FALLOUT. Any measure which lessens the amount of fallout arriving and depositing on or around buildings not only contributes to their shelter effectiveness but permits the earlier initiation of recovery operations and decreases the required recovery effort. Three general aspects of reducing the accumulation of fallout are discussed below.

a. *Aerodynamic Considerations*. The flight path described by fallout is produced by the [illegible] action of gravity and existing air currents. The resultant trajectory of fallout particles may become almost flat in the presence of strong winds. Except for particles of 1000 μ or greater, the angle of fall (relative to the horizontal) is generally less than 30 degrees at the nominal wind velocity of 15 knots. Estimated average angles of fall are given in table [illegible], together with the average falling velocities for spherical particles carried at various wind velocities from an initial altitude of 10,000 feet.

Table [illegible]. Flight Characteristics of Spherical Particles Falling From 10,000 Ft.

Particle Size (microns)	Average Falling Velocities in Still Air (ft/sec)	Angle of Fall (degrees)* for Various Wind Velocities (knots)			
		1	5	15	50
[illegible]	[illegible]	[illegible]	[illegible]	.92	[illegible]
100	[illegible]	[illegible]	[illegible]	7.1	[illegible]
400	[illegible]	73	57	27	9
1000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*Angle measured with respect to horizontal.

When air flows over a target area, obstructions such as buildings, trees and topographical irregularities disrupt the air stream, forcing sudden changes in direction and introducing turbulences. The unstable conditions created disturb the lift forces acting on airborne particles and could encourage the deposition of fallout material. Therefore, in

BEST AVAILABLE COPY

seems reasonable that fallout concentrations could be controlled if the potential patterns around target components were understood.

For buildings situated in an air stream, the region of most extensive turbulence (and hence the most likely region for accumulating fallout) is characterized by a low air pressure. The main body of this low-pressure eddy-region is located on the downwind side of the building.[1] A small portion of this eddy pattern may sometimes lie on the roof, also.

Experimental data lacking, the air-pressure/particle-deposition relationship cannot be estimated quantitatively. It can only be assumed that increases in the size and frequency of low pressure regions promote increases in the collection of fallout. Wind tunnel tests with numerous types of building models provide measurements of these pressure regions as a function of building geometry and orientation. The results as reported by Evans[2] furnish valuable clues (of a qualitative nature) to those building properties which might influence fallout deposition. The more significant findings are summarized below.

(1) Building geometry. In general, the size of the low-pressure region is directly proportional to building height, frontal width, and roof slope. Thus a flat-topped building having a square frontal area should provide the smallest pressure region. This is especially true if the building depth is two or more times the building height. Greater depth does not cause an appreciable enlargement of this low pressure region.

Roof overhang also affects the magnitude of the air pressure region. For instance, if a windward overhang is on the tall side of a shed roof, the low pressure region will increase. Eddy effects over low flat roofs may be reduced by long overhangs on the downwind side.

(2) Building orientation. Since pressure regions develop with increased frontal area, building orientation with respect to the prevailing wind must also be taken into account. Figures 5-10[2] and 5-11[2] show four basic building plans placed in various attitudes to a wind coming from the left side of the illustration. The orientations resulting in minimum low pressure regions (gray areas) are in brackets. Except for the U-shaped plan, this minimum condition exists when the building presents the least amount of projected sail area normal to the wind.

The smallest pressure region is that of the narrow rectangular plan at the bottom of figure 5-10. This substantiates the earlier conclusion concerning square front buildings that are at least twice as deep as they are tall. Other shapes no doubt exhibit highly desirable aerodynamic

1. A high-pressure region exists on the upwind side.
2. Reference 15 in bibliography.

properties; e.g., the cylinder and the dome. Although these configurations may be ideal in some isolated cases, it would be costly to integrate them into a building complex.

The behavior of wind and fallout patterns around a given building is further complicated by the presence of adjacent structures. Within a target complex, the size, spacing, and orientation of buildings with respect to each other represent factors known to affect wind velocities and pressures. For each complex undoubtedly there exists some optimum building placement scheme which is least conducive to the eddying of air currents and the deposition of fallout. Unfortunately, there is, as yet, no suitable experimental material dealing with this problem. Any comments on the expected behavior of airflow among buildings would be based solely on conjecture.

(3) Simplified design. Just as buildings disrupt the main air flow over a target area, numerous irregularities in the main outline disrupt the airflow over a structure. Saw tooth roofs, split levels, pocketed walls, external ducting, blower housings, light wells, high parapets, etc. all promote eddy currents and the collection of fallout. In general, construction with a minimum of irregularities both in profile and plan would diminish the amount of fallout deposited over a given structure.

(4) Collection of resuspended fallout. Because tall, wide, thin objects create the maximum downwind eddy regions, high, solid fences or thickly planted rows of shrubs might be used to deliberately collect fallout. When properly located upwind of important installations extensive networks of these baffles would intercept at least a portion of the resuspended fallout blowing over the surface of the ground. Such a system is probably more suitable in augmenting the protection to a single building or a small cluster of buildings.

Security fences already in existence around most military establishments might be readily converted into baffles by attaching continuous runs of canvas on the upwind side. Even low fences could serve to impede the movement of ground deposits of fallout in much the same way as snow fences.

b. Contaminability of Surfaces. Although such factors as building geometry, configuration, and orientation may influence the amount of fallout collection, the retention of this material is largely a function of the more detailed surface condition. Thus when exposed to the same contaminating environment, some construction materials will retain more fallout than others.

Unfortunately there are, at present, no direct methods for measuring fallout retention. Comparative estimates have been made on the basis of a more readily determined quantity, decontaminability. By definition, this quantity is inversely proportional to contaminability and is numerically

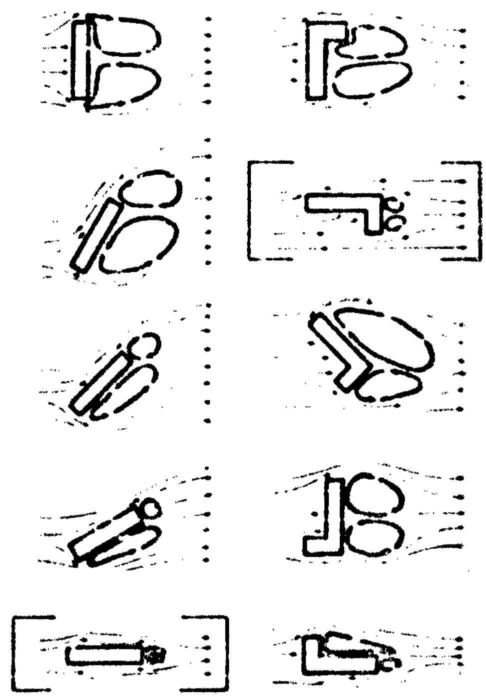

Figure 5-10. Building Orientation Versus Size of Turbulent Low-Pressure Regions (Grey Areas).

represented by the experimentally determined decontamination effectiveness values. Thus surfaces which are effectively decontaminated may be considered less contaminable than those that offer more resistance to the removal of fallout. It has, therefore, become customary to speak of the contaminability-decontaminability (C-D) characteristics together, even though only the latter is measurable at the present time.

(1) Wet fallout. Limited work has been done on a laboratory scale in measuring the variance in liquid holdup of different construction

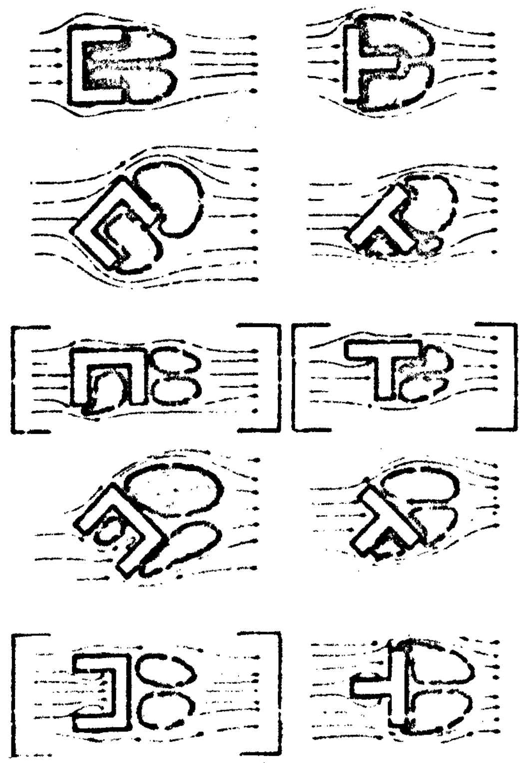

Figure 5-11. Building Orientation Versus Size of Turbulent Low-Pressure Regions (Gray Areas).

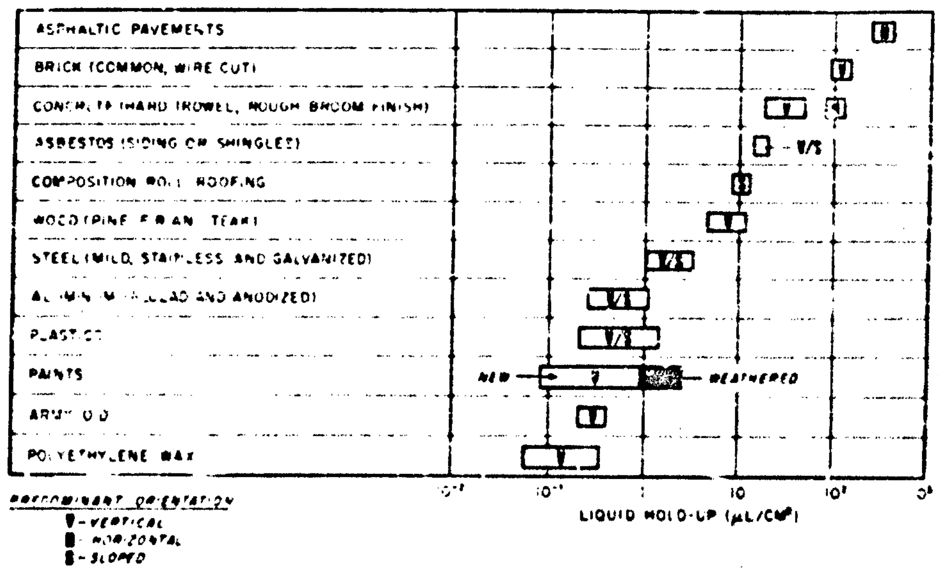

Figure 5-12. Relative Contaminability of Construction Materials by Wet Fallout as Determined by Liquid Hold-up Under Saturation Conditions.

materials when exposed to the saturating effects of a simulated rainout.[1] This test environment represented fallout resulting from an underwater detonation. Figure 5-12 presents the results of this one investigation. The amount of liquid hold-up was considered to be proportional to surface contaminability.

The decontamination information from laboratory and field experiments involving various types of fallout tends to verify the association between contaminability and surface condition illustrated in figure 5-12. That is, the more decontaminable materials possess one or more desirable surface characteristics; namely, hardness, smoothness, impermeability and chemical inertness. These characteristics are exhibited by the less contaminable materials in the lower half of figure 5-12.

1. Reference 10 in bibliography.

(2) Dry fallout. For the case of dry fallout, which is of greatest concern, smoothness is the controlling factor. There are two important aspects of surface smoothness: (1) the intimate texture of the building materials themselves, and (2) the general configuration of the surface system. Table 5-X takes both features into account by ranking a representative sampling of building materials and surfaces in their expected order of increased contaminability (decreased decontaminability). As an example, composition shingles rank below built-up roll roofing. Although the individual materials are identical, the shingles are separated by joints and, therefore, create the more contaminable surface.

Because of cost, unavailability or over-riding requirements, it may not always be possible to employ such preferred materials as metal, plastic, ceramics, etc., which head the list in table 5-X. Assuming that the materials appearing in the lower portion of these lists are unacceptable, the selection then becomes quite restricted. In order to alleviate this situation, improved ways of forming, joining and finishing those materials which are available must be developed. Several examples for achieving smoother surfaces are as follows:

(a) Pour concrete against steel or plywood forms.

(b) Sack concrete with gravel or a mixture of sand and cement and finish with a steel trowel.

(c) Make mortared joints flush with the bricks or tiles.

(d) Omit the course sand from the finish coat on stucco walls.

(e) Use cleanly surfaced wood siding, apply vertically, and calk all joints.

(f) Eliminate the gravel from built-up tar or asphalt roofing.

(g) Employ asphalt-base coatings and cements over roofs of concrete, calked wood decking, or plywood sheets having taped joints.

(h) Cement composition shingles along all edges and fair the joints with roofing compound.

The imaginative designer who is familiar with construction practice can probably think of numerous other ways of integrating common material into smooth-surface systems. In keeping with these efforts it is important to clean up the over-all design. That is, the elimination of cornices, ledges, sills and other unnecessary projections will further reduce fallout retention. This also means that some of the new and very attractive

Table 5-X. Approximate Ranking of Building Materials and Surfaces According to Increasing Contaminability.

Roofs

Plastic or Fiberglass - Flat or Corrugated Sheets.

Sheet Metal - Aluminum, Terne Plate, Tin, Copper, Lead, Zinc, and Galv. Iron (corrugated).

Masonite - Tempered.

Built-up - Prepared Roll (mineral surfaced) and Tarred Felt.

Aluminum Shingles - Plain or Enamel Finished.

Clay Tile and Slate Composition Shingles and Asbestos Shingles Concrete Shingles and Wood Shingles	of about equal contaminability

Built-Up - Tar and Gravel.

Walls

Glass, Ceramic or Plastic Panels

Metal Panels - Steel and Aluminum

Masonry Facing - Ceramic Tile and Glass Block

Masonite Panels - Tempered

Concrete - Poured, Sealed

Plywood - Marine Type, Sealed

Aluminum Shingles - Plain or Enameled

Stucco - Sealed Clay Tile - Structural Brick - Clay, Concrete or Cinder Stone - Structural or Facing Asbestos Siding or Transite Wood - Siding and Shingles, Stained	of about equal contaminability

surface treatments such as sculptured brick, combed wood, washed pebble concrete, etc., are not recommended.

Still another means for improving the C-D properties of building exteriors is the application of protective coatings. This subject will be discussed in the next section.

Nothing has been said so far about the retention of fallout on building surroundings. Because of their nearly horizontal attitude, most ground areas are quite contaminable, especially exposed soil and planted areas. Paved areas of concrete or asphalt are preferred. Because the rough texture of their surfaces must remain to insure the safe movement of traffic (pedestrians as well as vehicles), adequate drainage and the effectiveness of fallout removal methods must be relied upon to offset the inherent contaminability of pavements.

As in the case of roofs and walls, there are some acceptable substitutes for concrete and asphalt. Soil cement, oiled dirt, paving stones or tiles set in mortar, and wood planking are samples. Open ground, lawns, and planted areas are not always objectionable if they are far enough removed from buildings and other obstructions to permit the use of agricultural tools and earth-moving equipment during the anticipated recovery phase. The influence of slope will be covered in Section 5-03,a, Proper Drainage.

c. Protective Coatings. Radiologically speaking, a protective coating is any pre-attack surface treatment which improves the C-D characteristics of structural exteriors. Such a definition, however, embraces everything from dilute water repellents to heavy layers of grout. In practice the term protective coating has come to include only those relatively thin and tenacious films typified by paint and various sealers.

Considerable experimental work has been directed in a search for coatings that would answer radiological requirements. A large assortment of candidate coatings have been exposed to various types of radioactive contaminant (real or synthetic). In order to determine the amount of protection gained, the coatings were usually decontaminated and the results compared with the decontamination effectiveness achieved on unprotected surfaces.

Before discussing the findings from these experiments it is necessary to define "effectiveness" and "gain".

(a) Effectiveness is a gage of the decontaminating capability of a particular method or procedure on a given surface. It is often expressed in terms of the fraction of original intensity or contaminant remaining after decontamination:

$$F = R/I \qquad (5\text{-}01)$$

where R equals the residual level after decontamination and I equals the initial level prior to decontamination.

(b) Gain is the contribution of a protective coating toward increasing the decontaminability of a surface. It is determined from the ratio of fractions remaining thus:

$$\text{Gain} = F\ (\text{no coating})/F\ (\text{coating}) \qquad (5\text{-}02)$$

It is assumed that the gain also indicates the decrease in contaminability.

(1) Fixed coatings. From the many coatings tested only a few were found to contribute a significant amount of protection. These are listed in table 5-XI,[1] together with the base materials to which they were applied and the decontamination procedures used. The degree of protection provided by the coatings is indicated by the figures in the gain columns for dry, slurry[2] (nearly dry) and wet type contaminants. The latter two columns are included to supplement the small amount of gain information pertaining to dry contaminant. Since wet and slurry contaminants are more tenacious, any associated gains are assumed also to be achievable under conditions involving the more easily removed dry contaminant. Thus all the coatings listed in table 5-XI may be considered applicable to the dry fallout case - when limited to the materials and decontamination procedures shown.

With over half the table devoted to Navy 5H Paint, the selection of protective coatings appears pathetically small. In the case of paved surfaces this is particularly serious, since the effects of traffic are not known. Any one of the four coatings represented may have to be renewed periodically, thus increasing the cost of protection. More durable and trafficable coatings may be available, but their contribution toward the decontamination of pavements has not been determined.

Where buildings are concerned, table 5-XI[1] is not so restrictive. The rather large gains connected with Navy 5H paint indicates that any comparable top-grade paint should markedly improve the decontaminability of building surfaces similar to the ones shown. As to the other materials not covered here that appear in table 5-X, obviously, little gain would be expected from coating naturally smooth, hard, nonporous materials such as glass, ceramics, plastics or noncorrosive metals. Furthermore, no gains have been noted in attempts to protect the rough surfaces of built-up roofing with specially prepared coatings. The remaining materials, roofing tile, brick, and masonry, are the same as or equivalent to those covered in table 5-XI.

---

1. Reference 17 in bibliography.
2. Slurry was the name first given to fallout originating from a shallow water (harbor) burst. It has since fallen into disuse but will be retained here for the convenience of differentiating between the sets of values given in Table 5-XI.

Table 5-XI. Contribution of Protective Coatings in Terms of the Gain (G) in Decontamination Effectiveness (F)

Material	Procedure	Coating	Dry[a] F[b]	Dry[a] G	Slurry F[b]	Slurry G	Wet F[b]	Wet G
			Paved Surfaces					
Asphalt	Firehosing	Black Top Seal	.024	6.5	.036	2.7		
Concrete, Rough (Broom Finish)	Firehosing	Silicone Water-Repellent	.01	1.7	.08	2.5		
	Firehosing	Epoxy Resin Seal	.01	1.7	.08	3.3		
Concrete, Smooth (Troweled)	Powered Flushing	Water-Repellent	-	-	.114	2.4		
	Vacuuming	Epoxy Resin Seal	.035	2.1	-	-		
			Building Surfaces					
Concrete	Firehosing	Navy 5H Paint					.79	1.4
	Hand Scrubbing[c]	Navy 5H Paint					.92	6.5
	Hot Liquid Jetting[d]	Navy 5H Paint					.80	4.1
Stucco	Firehosing	Navy 5H Paint					.91	3.4
	Hand Scrubbing	Navy 5H Paint					.94	9.4
	Hot Liquid Jetting	Navy 5H Paint					.77	6.4
Wood Siding	Firehosing	Navy 5H Paint					.75	1.9
	Hand Scrubbing	Navy 5H Paint					.66	6.8
	Hand Scrubbing	Phenolic Resin					.84	1.8
	Hot Liquid Jetting	Navy 5H Paint					.69	4.1
Transite Siding	Firehosing	Navy 5H Paint					.90	2.3
	Hand Scrubbing	Navy 5H Paint					.95	12
	Hot Liquid Jetting	Navy 5H Paint					[illegible]	3.4
Corrugated Galvanized Steel	Firehosing	Navy 5H Paint	.035	2.7[e]			.78	1.4
	Firehosing	Army OD Paint	.035	2.1[e]				-
	Firehosing	Zinc Chromate	.035	1.6[e]				
	Hand Scrubbing	Navy 5H Paint					.97	7.7
	Hot Liquid Jetting	Navy 5H Paint					.74	4.3

a. Particle size: for paving, 75 % (by wt.) < 75 μ; for buildings, 90 % (by wt.) < 100 μ.
b. Effectiveness measured on surfaces not protected by coatings.
c. A prewetting, detergent-scrubbing, rinsing sequence.
d. High-temperature, high-pressure hosing with a detergent solution.
e. For roofs only. All other gain figures for building surfaces are from tests performed on vertical surfaces.

To date there have been no tests of protective coatings on these stone-like materials. However, a number of commercial coatings have been applied to concrete samples and have been given water absorption tests. Admittedly, surface roughness is considered to be controlling during a dry contaminating event, but, when wet decontamination methods are used, the absorption of moisture is not conducive to high effectiveness. Because tiles, bricks, stone, and similar materials exhibit a porosity and absorbability akin to concrete, these water absorption tests provide some clue to the protective potential of certain coatings.

In these tests concrete cubes were soaked in water for 24 hours. Uncoated samples averaged 3.7 percent absorption during this time interval. Most of the coatings tested lowered this figure, but none gave a value of zero. Table 5-XII[1] lists those coatings whose percent absorption tested less than or equal to that of Navy 5H Paint.

It was noted during these tests that all coatings, other than Flexseal, which is a water-repelling penetrant, visibly reduced the surface roughness in addition to reducing the absorbability. These coatings, then, appear to be candidates for the protection of masonry, concrete, and possibly clay tile surfaces. Nothing definite can be inferred without tests involving radioactive contaminant with defined physical and chemical properties. Nevertheless, such fragmentary information can be useful to the experienced designer who is already accustomed to weighing the more conventional factors of coating durability, fire resistance, cost, and maintenance.

(2) Removable coatings. The possible contamination of naval vessels by fallout has encouraged the development of a special class of paint, the removable coating. This type of coating is designed for use over standard paint. In theory, its selective removal leaves the base coat intact and relatively free of contamination. Effectiveness values of 0.1 to 0.05 have been obtained in actual ship recovery experiments involving tenacious wet fallout.

The most promising removable coating formulated thus far is an alkali base paint.[2] Its removal is accomplished in two steps:

(a) First the surface is sprayed with a 3 percent (by weight) solution of common boiler compound.

(b) After being allowed to act for 15 minutes the boiler compound is removed together with the coating by high pressure streams of water (salt or fresh).

---

1. Reference 18 in bibliography.
2. Mare Island Naval Shipyard formulation 4J440-36 (Reference 19).

Table 5-XII. Percent Water Absorption (by wt.) of Coated Concrete Blocks.*

Coatings	Percent Absorption	Manufacturer
Butvar in MEK - 25 %	0.3	Monsanto Chem. Co.
Colorfloor XX	0.3	Tremco Mfg. Co.
Armor Q	0.4	Armor Labs, Inc.
Pli-Namel	0.4	Glidden Co.
Porselon Aluminum	0.4	Protex-A-Cote, Inc.
Savincleum	0.4	Pa[illegible]noleum, Inc.
Dub-O-Lite	0.5	DeBoom Pa[illegible] Co.
Porcelon Clear	0.5	Protex-A-Cote, Inc.
Surfa Sele	0.5	Rust-Oleum Corp.
Ucilor 1701	0.5	United Chromium, Inc.
Armortec	0.7	Armor Labs., Inc.
Butvar 75 % - Epon 25 % in MEK - 25 %	0.7	Monsanto Chem. Co.
Flexseal	0.8	Flexrock Co.
Epon XA-200- 60 % w	0.8	Shell Chem. Co.
Armorloc	0.9	Armor Labs., Inc.
5H Haze Gray	0.9	U. S. Navy

*From Reference 13.

One hundred percent removal of this coating is possible at rates of 10 to [illegible] square feet per minute. Delivery pressures of 150 to 200 pounds per square inch are required. It is also necessary to use a special nozzle which [illegible] a thin fan-shaped stream having an included angle of 15 to 30 degrees. Removal is slower with conventional nozzles such as are used for fire streams.

Unlike so-called strippable paints, removable coatings break up into small pieces that are easily transported by fluid streams, and the paint residue is not likely to clog drains. Although it is believed that most painted surfaces can be effectively rid of dry fallout material, removable coatings are an added guarantee. Then too, removable coatings are a convenient and effective means of protecting against the possibility of more stubborn forms of fallout.

[illegible] FACILITATION OF RECOVERY OPERATIONS. It was explained earlier that protective features which reduce the collection and retention of fallout also enhance its subsequent removal. The contributions of general streamlining and detailed smoothing of target surfaces (discussed in the two preceding sections) toward facilitating decontamination are implicit in the illustrations and need not be treated specifically. However, certain additional features are directly related to the decontamination process and are discussed here.

a. Accessibility of Areas. The complete application of radiological protection principles would preclude the need for outside assistance, since the recovery operation would be manned by base personnel only. That is, recovery teams would actually consist of mission personnel already on base. [illegible] making a military base accessible from without is not generally considered a priority item on the schedule of the recovery effort. Of course, [illegible] equipped with street sweepers and street flushers [illegible] rapid mass removal of fallout from roadways extending beyond the base [illegible], when the situation [illegible]. It is envisioned, however, that the initial phase of recovery will be concentrated on those [illegible] within the [illegible] areas that are vital to its basic mission. To this end the accessibility of important buildings and adjacent areas is essential to their speedy and effective recovery.

(1) Accessibility of roofs. Because of the greater vulnerability of roofs to deposition of fallout (as compared to walls), ready access for the movement of men and equipment to roofs are desirable. Ideally, access should be from inside a building to prevent the tracking of [illegible] material into interior spaces. Fire escapes offer an excellent and permanent means of reaching the roofs of multistoried buildings, [illegible] the movement of decontamination equipment (such as [illegible]), [illegible] are not suitable. Fire escapes [illegible], of course, be extended to the roof.

Fixed vertical ladders, as found on many barracks-type structures, are adequate only when personnel are not carrying equipment. Firehoses and related items may be raised on ropes, if buildings are not too tall. Extension ladders (14 to 50 feet long) are also useful, and are safe for men and equipment when in the hands of trained personnel. Powered aerial ladders can be used for heights from 50 to 100 feet. Mobile cranes might also be employed for multistoried structures.

Low one-story buildings do not present much of a problem. Still, the accessibility of their roofs can be usually improved by the addition of inexpensive but permanently installed slanted ladders. Fork lifts, when available, represent another means of placing people and decontamination gear atop low buildings, including even some two-story structures.

Fire companies outfitted with tower trucks, powered extension platforms, and similar devices, may be enlisted to put recovery crews on some roofs. Where firehosing is judged to be effective, such equipment can be used to wash roofs from alongside buildings. Roofs having a pronounced pitch may be effectively decontaminated by lobbing fire streams from the ground. For tar and gravel roofs, hosing must be conducted at roof level to insure the complete removal of loose gravel, which tends to impede the transport of the fallout deposits. Because tar and gravel roofs have very little slope, firehosing may be performed atop the roof in comparative safety.

(2) Accessibility of ground areas. For a recovery effort comprised of manual methods, such as firehosing, scrubbing, spading, etc., most building grounds and surrounding areas will be readily accessible. This may not be the case for a recovery operation based largely on motorized methods. Since mechanized recovery results in less radiation exposure of personnel, by virtue of the increased shielding and reduced stay times, critical areas must be made accessible to motorized equipment. For this reason planners of military complexes should be generous in dimensioning streets, parking areas, yards, and dividing strips between buildings to allow freedom of movement of heavy equipment.

The space required to maneuver a piece of motorized equipment is determined by the width of 180-degree turns. This, of course, is dependent upon equipment size. Figures 5-13 and 5-14 depict the increase in turning width as a function of increased hauling capacity (or size), for street sweepers and scrapers, respectively. Differences in design account for the broad trends shown.

Since the capacity of popularly used sweepers is usually 3 or 4 yards, figure 5-13 indicates that streets ought to be at least 30 feet across to permit turning between intersections. Where larger sweepers are expected to be used, widths will have to be increased even more.

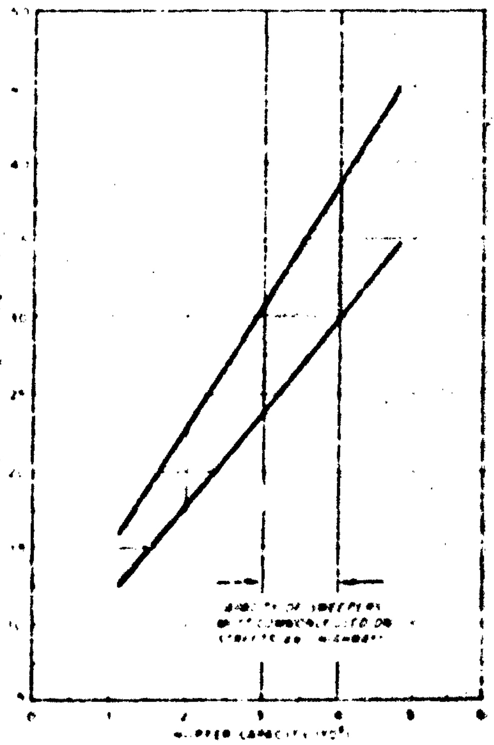

Figure 5-15. Approximate Turning Width of Motorized Street Sweepers as a Function of Their Capacity to Carry Debris.

The spacing of buildings separated by unpaved areas may be judged from the turning widths of scrapers given in figure 5-14. It is apparent that the tractor-drawn scrapers, being considerably more maneuverable than the self-propelled variety, would permit closer grouping of buildings. Assuming the larger sizes are to be used for heavy duty (such as digging and filling, disposal pits), a [illegible]-ft spacing between buildings should accommodate most scrapers having capacities up to 15 cubic yards. For more confined areas, dozers, skip loaders and agricultural and landscaping equipment are effective tools for the removal of contaminated soil.

Self-propelled scrapers and road graders may be used in making long cuts requiring no short turns. The turning width of graders varies from 55 to 80 feet, depending on the design.

Advantage should be taken of the cleaning potential represented by the small industrial sweepers. As can be seen from the graph of turning width versus capacity in figure 5-15, these machines will reach areas that conventional sweepers cannot. Driveways, walks, courts, exposed corridors and open interiors are accessible to industrial sweepers. By substituting ramps for stairs, elevated areas such as loading platforms and functional docks can also be made accessible. Then too, ramps are more easily flushed and drained than stairs, if decontamination by hosing is found preferable.

Many areas accessible from the standpoint of size have obstructions which restrict motorized methods. Utility sheds, pump houses, service poles, lamp posts, trees, shrubs and service meters are common obstacles to the movement of heavy equipment. Interference can be minimized by placing such facilities within the main buildings, where possible. Some fixtures can be eliminated or located to provide the proper clearances.

Security fences should be placed so as not to hinder mechanized recovery operations. Roll curbs, ramps and reinforced walks will further facilitate the movement of heavy equipment into areas not normally made accessible.

When plowing will be employed to bury contaminated earth, underground obstacles such as service lines must be sunk out of blade reach or their locations plainly marked. In addition, the ground should be prepared for easier tilling by removing the larger rocks (those beyond the pebble size). This precaution will also reduce spillage during scraping operations. Scraping may be further improved by encouraging the formation of sod in unpaved areas. This permits lighter cuts, improves loading, and reduces the amount of spoil that must be hauled to the disposal area.

b. Adequate Water Services. In the removal of fallout from buildings and paved areas, firehosing is probably the most adaptable and effective method universally available. Fortunately, the water consumption of a recovery operation consisting largely of firehosing is not expected to exceed the capabilities of a properly designed, modern fire fighting system. The main components of any fire system required to support recovery by firehosing are the water reserves, the arrangement of distribution lines, and the location and capacity of the hydrants.

To effectively firehose a given facility, approximately one gallon of water will be expended for every square foot of surface decontaminated. The total consumption in gallons will then approximate the number of square feet of roofs and paved areas. The volume of water that should be available in reservoirs, tanks or wells need not match this amount. The duration of

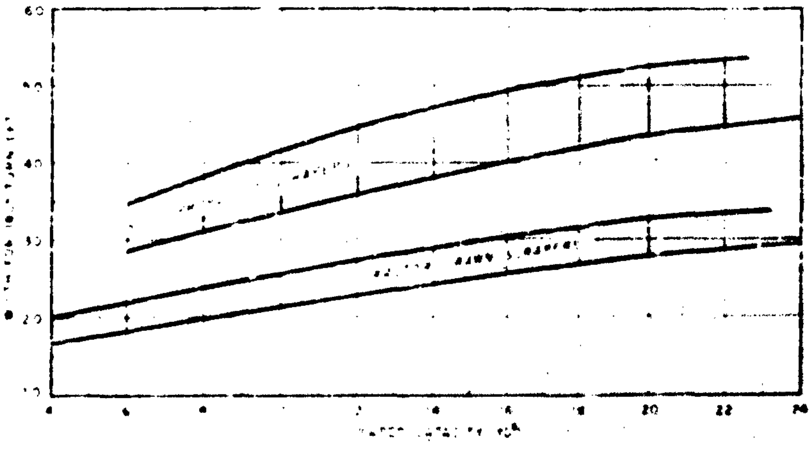

Figure 5-14. Approximate Turning Width of Scrapers as a Function of Their Capacity to Haul Earth.

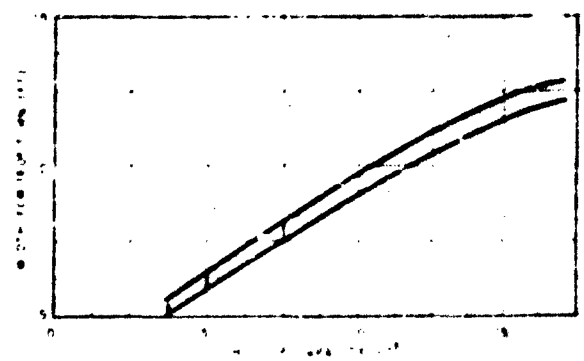

Figure 5-15. Approximate Turning Width of Industrial Sweepers as a Function of Their Capacity to Carry Debris.

the firehosing operation will depend upon the urgency of the situation and the effort assigned. Therefore, the water supply need be only large enough to keep pace with the rate of consumption rather than equal the total volume expended.

Table 5-XIII shows the required amount of water for fire service in the average city, computated from the National Board of Fire Underwriters formula[1] based on population size. The daily consumption for normal water requirements must be added to these rates. Although not directly applicable to military establishments, the tabled values indicate the magnitude of the water supply problem for either fire fighting or radiological recovery.

Table 5-XIII. Water Requirements for Fires in Average American City.

Population $\times 10^3$	Fire Flow (10^3 gpm)	Fire Flow (10^6 gpd)	Duration (hr)
1.0	1.0	1.44	4
1.5	1.25	1.80	5
2	1.5	2.16	6
3	1.75	2.52	7
4	2.0	2.88	8
5	2.25	3.24	9
6	2.5	3.60	10
10	3.0	4.32	10
13	3.5	5.04	10
17	4.0	5.76	10
22	4.5	6.48	10
28	5.0	7.2	10
40	6.0	8.6	10
60	7.0	10.1	10
80	8.0	11.5	10
100	9.0	13.0	10
125	10.0	14.4	10
150	11.0	15.8	10
200	12.0	17.3	10

1. Reference 20 in bibliography.

The most satisfactory piping arrangement for distributing water is the gridiron stystem in which all lines are cross-connected at street intersections. By the manipulation of control valves, a grid system can be made to supply water to a vital area from several directions at once. In the same manner, serious breaks can be isolated and by-passed without loss of pressure to the rest of the network. Grid mains less than 8 inches in diameter are no longer considered adequate. Diameters of 12 inches or more are recommended for long runs of pipe uninterrupted by cross-connections.

The hydrant is a very necessary fixture in the fire system. In order that hydrant performance be consistent with a well designed system, the National Board of Fire Underwriters and the National Fire Protection Association have suggested the following standards:

(1) At least one hydrant be located near each street intersection. For blocks longer than 400 feet, an additional hydrant required midway between intersections.[1]

(2) Hydrant capacity to range from 500 to 3000 gallons per minute or more in direct proportion to the density and importance of buildings in the area.

(3) Hydrant pressure to approximate 75 pounds per square inch. Booster pumps will be needed for most hosing procedures due to line losses and high pressure requirements.

(4) (American) National Standard threads recommended to insure making connections between hose and hydrant.

Although federal specification WW-C-621a[2] requires standardization of hose threads within the armed services, it only partially complies with the fourth recommendation. For instance, the federal specifications match those of the American National Standard in the 2-1/2, 3 and 3-1/2 inch thread sizes. A special design is given for 4 inch thread, and parallel iron pipe threads are specified for 1 to 2 inch sizes. These and other comparisons may be drawn from tables 5-XIV and 5-XV which show some of the many thread standards being used throughout the United States.

Thus the consistency of thread sizes among the armed services does not guarantee their compatibility with the standards chosen by civilian agencies. During a recovery operation it may be desirable to temporarily increase the delivery of one facility's fire system by borrowing pumpers, hoses and auxiliary equipment from fire companies located nearby. This is feasible only if an interchangeability of threaded connections exists

1. Hydrants should be kept back from curbs, preferably next to buildings, to avoid the obstruction of mechanized reclamation equipment.
2. Reference 21 in bibliography.

Table 5-XIV. Fire Hose Thread Specifications*
(Maximum O.D. of Male Thread/No. Threads per Inch)

Thread Standard Designation	Nominal Thread Sizes (Inches) 1-1/2	2	2-1/2	3	3-1/2	Ref.** No.
Federal Service - Army, Navy & Air Force	1.8788 / 11-1/2	2.3528 / 11-1/2	3.0686 / 7-1/2	3.6239 / 6	4.2439 / 6	21
U.S. Forest Service	1.8788 / 11-1/2	2.3528 / 11-1/2	2.8550 / 8	-	-	22
U.S. Straight (Parallel) Pipe Thread	1.8788 / 11-1/2	2.3528 / 11-1/2	2.8550 / 8	3.4700 / 8	3.9700 / 8	22
American National Standard (NFPA)	1.990 / 9	2.5220 / 8	3.0686 / 7-1/2	3.6239 / 6	4.2439 / 6	23
Pacific Coast	2.100 / 11	2.5500 / 10	3.0350 / 7-1/2	-	-	22
Eastern	2.125 / 11	2.6719 / 7-1/2	-	-	-	22
Chicago (Crane)	1.946 / 11-1/2	2.522 / 8	3.043 / 7	-	-	22
Chicago Fire Dept.	1.946 / 11-1/2	-	3.0156 / 7-1/2	-	4.070 / 8	22
NY City Fire Dept.	2.100 / 8	2.530 / 8	3.030 / 8	3.630 / 8	4.070 / 8	22
New York Corp.	2.093 / 11	2.547 / 11	3.000 / 8	-	-	22

* Threads are of the 60° type.
**In bibliography.

Table 5-XV. Suction Hose Thread Specifications*
(Maximum O.D. of Male Thread/No. Threads Per Inch)

Thread Standard Designation	Nominal Thread Sizes (Inches) 4	4-1/2	5**	6**	Ref. No.***
Federal Service - Army, Navy & Air Force	4.9082/6	-	-	-	24
U.S. Straight (Parallel) Pipe Thread	4.4700/8	4.9133/8	5.5313/8	6.5880/8	22
American National Standard (NFPA)	5.0109/4	5.7609/4	6.2600/4	7.0250/4	23
N.Y. City Fire Dept.	4.610/4	5.800/4	-	-	22
Ahrens-Fox	-	-	6.2100/4	7.000/4	22
American La France	[illegible]/4	-	6.150/4	[illegible]/4	22
Barton Pump	[illegible]/4	-	-	-	22
Buffalo Fire Appliance	4.97[illegible]/4	-	6.225/4	6.975/4	22
Mack Manufacturing	-	-	[illegible]/4	[illegible]/4	22
Seagrave	[illegible]/4	-	6.052/4	7.048/4	22

* Threads are of the 60° type.
**Not recommended by NFPA for hydrants.
***In bibliography.

between the various fire departments representing military establishments and the neighboring agencies, towns and counties. Until an acceptable thread standard is adopted by those fire organizations that might assist one another, each must stock a wide assortment of special thread adapters. The eventual acceptance and use of a single national standard would, of course, obviate this requirement and the problem of interchangeability.

In addition to the distribution of water through street mains and hydrants, important structures are given added fire protection through standpipe systems with outlets on every floor. For recovery purposes the roof is of primary concern. Therefore, a simplified and inexpensive design consisting of a single standpipe having one or more roof outlets and sheltered hose racks should be sufficient. Such an arrangement would eliminate stringing long runs of large capacity (2-1/2 to 3 inches) delivery hose from curb hydrants to roof. A ground connection to the standpipe should be provided to permit the use of booster pumps for increasing the water pressure at roof outlets. Nozzle pressures of 60 to 80 pounds per square inch will be required.

c. Proper Drainage. The degree of transport of fallout particles by run-off from wet removal methods depends much upon the existing drainage conditions. On relatively flat areas the particles settle out and redeposit on the surface, thus requiring repeated decontamination passes and additional volumes of water. On positive slopes, sufficient velocities may be established in the run-off water to promote the mass transport of fallout. In general, steeper slopes will provide for faster transport of more fallout material at reduced water consumption rates. Thus surfaces such as roofs, grounds and streets should be given as much slope as can be reasonably tolerated in their routine functions.

(1) Building Roofs. For practical reasons most roofing materials are installed at a pitch of 1 in 6 or steeper. Such slopes provide the drainage required in the removal of anticipated quantities of fallout. Built-up roofs represent an all too frequent exception, since they seldom are sloped more than 1 in 6. Where roofs are relatively flat, tar and gravel surfaces are used almost exclusively. Obviously a rough, graveled surface having little or no slope will resist the mass transport of particulate fallout by the flow of run-off water. This condition can, of course, be improved by a better choice of roofing materials (see Section 5-03, b). However, the mere substitution of materials does not obviate the need for a positive slope, even for an ideally smooth surface.

Tests were recently conducted on the transport of particulate matter by a thin water film along a 26-foot long plate glass plane.[1] For slopes close to zero (1 in 1500) and water flow rates under 10 gallons per minute per foot of width,[2] the particle velocities were thousandths of a foot per

1. Reference 25.
2. The width is the dimension perpendicular to the direction of flow.

second. This is comparable to the removal of about one gram of material per minute per square foot, an extremely slow transport rate. Firehosing flat tar and gravel roofs will remove over 100 grams of fallout per minute per square foot, plus an estimated 450 grams of loose gravel per minute per square foot.

With the glass plane set at a slope of 1 in 24[1] (the minimum normally recommended for flat roofs), the mass removal capability increased by a factor of 100 while the flow rate decreased by a factor of 10. This trend continued for still steeper slopes.

Since roofing materials are much rougher than glass, it is readily apparent that the designer of protective construction must give all proposed flat roofs as prominent a slope as the affected building elements will allow. If gravel is excluded from low-pitched built-up roofs, a slope of 1 in 24 may be considered an absolute minimum for the smoother surface systems. Because the rate of mass transport by the run-off water should ideally approach the loosening rate of the impinging firestreams, slopes considerably greater than minimum are desirable. Without further testing, neither the optimum nor the minimum slopes can be established for roofing materials.

In keeping with good drainage requirements, run-off water plus fallout particles must have a means of clearing the roof. For most pitched roofs there is no problem - the water can simply pour off the eaves onto the area below. It is assumed that the surface receiving this run-off, whether it be another roof or the surrounding grounds, will in turn have adequate drainage characteristics.

To prevent the contaminated water from running down building walls a moderate roof overhang should be provided. This may not be too effective where the wind can catch the run-off and blow it against the walls. Any exaggerated extension of the eaves to alleviate this situation for low buildings of one or two stories, however, might encourage the increased deposition of fallout (prior to recovery) at the base of the buildings (see section 5-02,a). For taller structures, long roof overhangs would protect the walls of the upper stories. Where the threat of contamination to a building's sides still remains, the designer is obligated to provide walls that constitute smooth surface systems capable of being easily decontaminated by fire streams.

Enlarged rain gutters may be installed at the eaves to intercept the run-off and control its flow to the ground. Special attention must be given to the fabrication of the down spouts to avoid their becoming clogged by the large quantities of solids washed from the roof. Gutters should be hung at slopes greater than 1 in 16 to promote the swift flow of material throughout the system. This type of installation is discussed more fully in subsection 5-04,a,1 in relation to washdown water return requirements.

1. Reference 26 in bibliography.

(2) Ground levels. Unlike roofs, the various slopes found at ground level within a target complex largely will be dictated by the existing topography. In hilly locations advantage may be taken of the natural drainage. Flatter sites may be altered to a limited degree by grading. In either case, drainage can be improved through the generous use of paved areas to form a reasonably smooth surface system. This applies particularly to those sensitive regions adjacent to important structures. Here the paved grounds should extend (uninterrupted by lawns, planter beds and other landscaping) from the foundation to curbs, gutters, ditches, or drain basins - whichever is most appropriate. The span of these paved areas will vary from narrow walks to aprons 30 feet or wider depending upon the proximity of streets, buildings, and other structures.

As in the case of roofs, a slope of 1 in 25, or 4 percent, may be taken to be the lower limit. Where the terrain permits, steeper slopes are preferred, especially for the broader expanses of pavement found in yards and parking lots. An exception may be sidewalks. To accommodate foot traffic and still drain the run-off due to natural causes, the cross-slope of walks is usually 1 percent or more. For walks under 8 feet wide and bordered by curbs or ditches, slopes of this magnitude will meet the drainage requirements of wet decontamination methods.

Streets, like walks, are generally given just enough crown to provide the necessary drainage to the shoulders without inconveniencing traffic. This cross-slope ranges between 1 and 3 percent.[1] In order to transport bulk quantities of fallout material with firehoses or street flushers a slope of at least 3 percent from centerline to roadside is most desirable. All streets should, therefore, be given the maximum crown allowable, particularly where 4 or more lanes are planned.

As streets and the paved areas beyond are washed free of the particulate contaminant, hundreds of pounds of this material will be deposited in the gutters. Its effective transport by the run-off water to the sewer inlets will require gutter grades that are at least equal to the pavement cross-slope, 3 percent or greater. If gutter grades are less than the cross-slopes provided by the road crown, water in addition to that used to decontaminate streets and sidewalks may be needed to flush gutters and inlets.

Gutter grades are normally established by the grade of the roadways. For this reason, grades of less than 0.5 percent are possible,[1] where streets run over relatively flat terrain. In such instances drainage will not be adequate. According to the Manning formula, a slope of over 1 percent is required for a conventional gutter to handle 100 gpm.[2] Since this

1. Reference 27 in bibliography.
2. The calculation assumes a 3 percent cross-slope due to crowning and permits flooding of the street out to 3 feet from the curb.

is a very moderate flow rate to ... means must be found to improve ... of street. One obvious solution ... drain (or sewer) inlets. Although ... of 300 feet[1] is recommended for catch ... be placed no further than 300 feet apart. ... curb-opening inlets are recommended, regard... maximum water flow conditions.

The problem created by minimum-slope streets ... in still another way. If gutters are formed like ... ered with steel gratings, they can be sloped independen... installing intermediate curb inlets between street inter... gutter slopes can be as steep as desired. Although this multiple outlet design is more expensive than either compone... improved drainage will further reduce the water requirements. ... run-off from recovery operations will transport a greater percent... gutter sediment without additional flushing. The decrease in ... of water in short supply may more than justify the added expense o... gutter and inlet systems.

(3) Disposal systems. It is not likely that a well-planned sewer and storm drainage system will be taxed beyond capacity by the amount of water used during decontamination operations. However, the introduction of large amounts of solids in the form of contaminated dirt will probably cause filling of catch basins and a build-up of deposits in the sewer drains. Once solids enter these lines, flow velocity becomes the controlling factor in preventing the formation of deposits. In the day-to-day performance of sewers, good design dictates a minimum flow velocity of about 2.5 feet per second in combined and 2.0 feet per second in separate systems. The minimum grades providing these velocities are given in the following tables for a number of pipe sizes when lines are flowing full or at half depth.[1]

Pipe Diameter (in.)	Grade (%) 2.0 fps	Grade (%) 2.5 fps
8	.58	.90
10	.41	.63
12	.31	.47
15	.22	.34
18	.17	.26
20	.14	.22
22	.13	.19
24	.11	.17
27	.09	.14

1. Reference 27 in bibliography.

Larger lines, such as those used for intercepting sewers and for combined sewers, are generally sloped to give still greater velocities; i.e., from 3 feet per second for 36-inch pipe up to 6 feet per second for 72-inch pipe. These, together with the previous minimum velocity values, are suitable lower limits for moving the normal concentration of solids - which is usually less than 0.1 percent (by weight) of the total flow. It is possible that the introduction of fallout materials could cause concentrations of 10 or 100 times this amount. Therefore higher velocities and hence steeper grades are desirable, if sewers are to be kept clear of sediment. The other alternative is to flush lines frequently to reduce concentrations of solids. However, this may deplete the supply of water needed for basic decontamination.

Assuming that sewer lines can be kept free of deposits, tremendous amounts of fallout material will eventually arrive at the sewage processing plant. It will be necessary to by-pass this point and send the radioactively contaminated flow to a remote disposal area. Where targets are served by separate sewer and storm systems, in all probability sewage can be received and processed in the normal manner. In this instance storm drains would transport the bulk of fallout particles removed during recovery and discharge it at a chosen disposal site. All this brings up the problem of waste disposal which is beyond the present scope of the handbook.

Another special problem may arise from the accumulation of contaminant in catch basins. Depending upon the volume of the basin and the specific activity of the fallout, the radiation field could build up significantly directly above a catch basin at street level. Three possibilities for handling this situation are:

(a) Roping-off the area centering over the catch basin out to several feet as dictated by gamma survey readings and the prevailing radiological safety requirements. This would interfere with traffic until the radiation field decreased to an acceptable level.

(b) Preventing deposition of contaminated dirt in catch basins. Temporary covers could be placed across basins flush with drain lines, or they could be filled with clean sand prior to arrival of fallout.

(c) Placing temporary shielding around curb inlets and manhole covers until the radiation intensity is reduced to a safe level.

The actual removal of any sizable accumulation from unprotected basins would have to be delayed until the radiation intensity decreases sufficiently by decay and/or remote dilution techniques. It is conceivable that earlier removal could be accomplished with motorized methods utilizing special trucks equipped with scavenging devices and waste tanks. Such an operation would require considerable shielding of crews.

(4) Summary. The importance of slope to the transport of particulate matter in water cannot be over-emphasized. Unfortunately the relation between mass removal rate and fluid flow rate as determined by slope is not well defined for structural surfaces. Some experimental results pertaining to roof washdown systems are forthcoming, but other critical surfaces remain untested. Until more research can be initiated it will be necessary to rely on the standard formulas of hydraulics to fix optimum flow conditions in the hope that these conditions will be conducive to the transport of fallout material.

5-04. SPECIAL DEVICES. Thus far radiological recovery has been discussed in terms of manned operations. However, three devices can be actuated remotely to effect the removal of fallout from sensitive surfaces: water washdown systems, air blowdown systems, and removable coverings. Because these systems intercept the fallout as it deposits out, their beneficial effects are felt sooner than those of the later recovery effort. This results in significant savings in dosage to persons manning facilities so protected. Suggestions for the design, installation and operation of such devices are given in this section.

a. Roof Washdown System. In principle, a washdown system covers the roof with a moving film of water which intercepts the arriving fallout and transports it to a disposal area. Although in different situations the fallout may vary considerably in physical and chemical properties, the particulate and insoluble fallout, characteristic of land surface detonations, is the type most difficult to transport by washdown system. Depending upon weapon yield and downwind distance from ground zero, the size and number of fallout particles could vary considerably. The mean diameter of a particle may range from about 50 microns (0.002 inch) to hundreds of microns. The total mass of material per square foot may be as much as 200 or 300 grams, arriving over a period of several minutes to several hours.

Because of this wide range of particle sizes and mass loadings, the washdown water must be capable of transmitting a complex loosening and propelling action to every square foot of contaminated surface. For instance, through fluid turbulence the lighter particles can be suspended and swept away by the current. Sufficient stream momentum will supply the necessary force to roll and slide heavier particles along the surface. Most of the fluid properties required in an effective washdown system can, to some extent, be created, augmented, and controlled through a well-integrated design.

(1) Basic Design. Once activated, a roof washdown system should be capable of operating for several hours unattended. The system may incorporate [illegible] of the washdown water to eliminate dependence on outside water supply systems. Unless emergency electrical power is available, pumps should be gasoline or diesel engine-driven.

A roof washdown system (Figure 5-1) consists of four components: water distribution, storage and collection, water return, and roof surface.

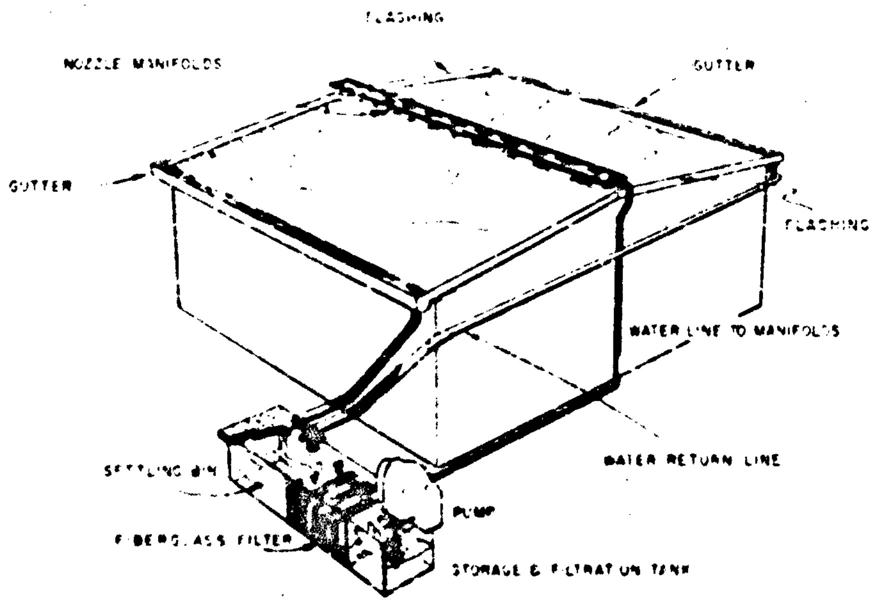

Figure 5-16. Recirculating Roof-Washdown System.

(a) Water distribution. The water distribution component consists of a pump(s), valves and pressure regulators, headers, manifolds and nozzles or orifices. Gasoline or diesel engine-driven pumps are commercially available in the range of 100 to 10,000 gallons per minute. Valves and pressure regulators control the flow of water. Pressures of 10 to 20 pounds per square inch are required in the nozzle manifolds. [illegible] to carry the water to the manifolds on the roof should be standard steel pipes.

One distribution system that has proved successful consists of a water delivery manifold suspended 6 to 12 inches above the roof and parallel to the roof ridge. Commercial nozzles that furnish a fan-shaped water jet are spaced along the manifold at 2 foot intervals. This arrangement will provide cleaning action approximately 50 feet down slope for most roof surfaces, tar and gravel roofing being the main exception.

The removal capability of this distribution system can be improved by the introduction of turbulences in the flowing water film. This may be accomplished by interspersing oscillating sprinklers along the manifold. The impaction of the rain-like droplets will create the agitation required to resuspend the more sluggish soil particles for continued transport down slope.

(b) Storage and collection. The storage component for the recirculating water includes the proposed collection component. One or more baffled settling basins allow the bulk of the solids to settle out under the influence of gravity. To protect the pump from fine particles that might remain suspended in the flow, a series of fiberglass filters could be installed. They should be arranged like baffles so that fallout particles clogging the filters will not stop the recirculation of water within the system.

The water storage capacity should be at least 10 times the volume circulating at full operation. Such a volume would allow for detention time, evaporation, and spray losses during operation. The storage pool should be subsurface to facilitate gravity return and to provide shielding against the trapped fallout. Water in the pool itself will constitute an excellent shield against any radiation from fallout material that has settled along the bottom. The pool also could provide emergency fire fighting or process water during domestic emergencies.

In an area of locally available water (ocean, lake or river) a once-through washdown system is feasible. This design eliminates the storage and collection components, and the waste water flows to storm drains. The waste disposal problem this may create would be no more serious than that resulting from conventional decontamination of surrounding surfaces during the recovery phase.

(c) Water return. The water return component should consist of gutters and leaders capable of carrying the water from the roof to the storage pool. The size of gutters depends upon the roof span, as follows:

Roof Span (ft)	Gutter Width (in.)	No. of Leaders (per 40 ft)
- 50	6	4
50 - 75	7	5
75 - 100	8	5

These widths have been found satisfactory by the American Bridge Co.[1] in handling the normal run-off from metal roofs - providing the required number of downspouts and leaders are used and the gutter slope is approximately 1 in 16. Since metal roofs represent a worst case (maximum flow) the tabled gutter widths should more than handle the less swift run-off from rougher roof surfaces. To insure the steady transport of the fallout material to the settling tanks a more prominent gutter slope is recommended, 1 in 10 or greater.

To further enhance the movement of water and fallout, gutter surfaces, including joints, should be smooth. Metal or metal-lined gutters are best. Sharp bends should be avoided. In order to control the discharge into the gutters, it may be advantageous to roll the edges to the roof.

(d) Roof surface. The roof surface component is an important part of any washdown installation. The condition of the surface, as determined by the roofing materials, and its slope contribute to removal effectiveness. In early roof washdown experiments,[2] the tracer particles used collected in the grainy texture of coarse materials, behind minor projections, in joints, and along seams. Therefore the principles for minimizing contaminability through smooth uncluttered surfaces having a minimum of exposed edges are especially applicable here.

Roof slope is essential to maintaining sufficient momentum in the washdown flow. Steeper slopes give increased velocity to the water film and hence greater removal power. Because of variations in roughness, roof surfaces do not all require the same slope to achieve a comparable degree of decontamination.

1. Reference 27 in bibliography
2. Reference 28 in bibliography

Table 5-XVI contains the results of small-scale washdown tests[1] performed on panels representing three types of roof surface. The surface roughness varied; in order of smoothness they were masonite, roll roofing, and composition shingles. Entries represent removal effectiveness in terms

Table 5-XVI. Influence of Roughness and Slope on Roof Washdown Effectiveness

Slope	Fraction Remaining		
	Masonite (1.3 gm/ft)	Roll Roofing (2.7 gm/ft)	Comp. Shingles (2.7 gm/ft)
1 - 4	.0[illegible]	.022	.003
1 - 12	(.015)	(.040)	.240
1 - 1[illegible]	.011	.004	.535
1 - 25	.020	.350	-

of the fraction of the total fallout deposit remaining (see Equation 5-01, section 5-02,c). It is evident that effectiveness increases (fraction remaining decreases) as the surface roughness [illegible] and the slope becomes steeper. The values in parentheses were duplicated earlier in limited full-scale tests[2] on roof panels measuring 30 feet down-slope. This tends to verify the application of the tabled values to actual building roofs, for the two [illegible].

Because washdown effectiveness depends upon complete surface coverage, [illegible] materials [illegible] cannot be satisfactorily protected by water films. A large portion of corrugated surfaces and

1. Reference [illegible] in bibliography.
2. Reference 30 in bibliography.

inverted V-type joints project above the flow, thereby preventing full coverage. But even flat surfaces may be difficult to cover, if they are inherently non-wettable. For instance, some extremely smooth materials resist the wetting action of water films. As was observed during experiments on an aluminum roof panel,[1] washdown water separated into distinct rivulets and left large areas unprotected. This condition was overcome by an extravagant increase in flow rate. To achieve 95 percent water coverage in these tests, the flow rate on the aluminum exceeded those on roll roofing and on tempered masonite by factors of 5 and 11, respectively, for a roof slope of 1 in 12. These figures were reduced only 50 percent when the slope was increased to 1 in 4. Thus, to insure washdown coverage and at the same time minimize water consumption, the criteria of wettability will control the choice of a smooth roofing material.

From the incomplete experimental data now available, tempered masonite exhibits the best combination of smoothness and wettability. Per table 5-XVI, the washdown consistently provided greater protection to the masonite than to the other two surfaces. In addition, this material required only 2/3 as much water. The fact that masonite was not originally intended as a roofing material should not prevent serious consideration of it (or some other material with similar characteristics) for washdown roof surface systems.

Even though a high removal effectiveness (98 percent) was achieved on masonite at the very low slope of 1 in 25, washdown is not recommended for use on lesser slopes. If the more common roofing materials are employed, table 5-XVI indicates that slopes of 1 in 4 or greater are needed to attain high washdown effectiveness.

Because smooth materials, such as metals and plastics, have proved consistently easier to decontaminate than most roofing materials, the possibility of improving their wettability should not be overlooked. The injection of wetting agents into washdown water offers some promise. Such an agent will reduce the surface tension in the water film so that it spreads evenly over the smoother and more decontaminable surfaces. Limited results from tests of water films flowing over a glass plane indicate that the addition of small concentrations of household detergent to the water supply significantly increases the transport velocity of particulate material falling on the test plane. It is very possible that better wetting of the particles themselves contributes to their fluid transport.

Preliminary runs during the latest washdown tests show that coverage of aluminum is improved by texturing the surface. A wavy line design was impressed on the panels to give them a simulated wood grain. Although there is no data to support this conjecture, it is possible that weathering of certain metals would give enough tooth to the surface to promote the necessary degree of wettability.

1. Reference 30 in bibliography.

Test results to date provide no basis for predicting the performance of washdown on materials other than the three shown in table 5-XVI. These results are limited, in turn, to the respective flow rates tested.

(2) Significance of washdown. The roof washdown concept is unique in that it offers an automatic means for decreasing the radiation intensity within buildings. This is possible since the washdown, unlike other recovery methods, operates remotely and at peak efficiency during the actual fallout event. Although its purpose is to achieve optimum removal effectiveness, a decision to install a washdown system should be based on its role in the over-all protection offered building occupants - in terms of reduced dosage. This does not mean that decontamination effectiveness is no longer influencing. As will be shown below, "roof fraction" as well as removal effectiveness determine the dose (or dose rate) reduction.

(a) Dose reduction factor. To estimate dose reduction factors when making design decisions, it is necessary to calculate the building interior radiation intensity both with and without protection of a washdown system. The radiation intensity I within a structure is, for all practical purposes, the summation of two separate intensities, I_R and I_G, contributed by roof and ground contamination, respectively.[1] The wall contribution, it will be remembered, is assumed to be so small by comparison as to be negligible. Thus the building intensity without washdown is

$$I = I_G + I_R \qquad (5\text{-}03)$$

and with washdown is

$$I' = I_G + F\, I_R \qquad (5\text{-}04)$$

where F is the washdown effectiveness or fraction of fallout remaining on the roof. The dose reduction factor is equal to the ratio of I'/I. Dividing equation 5-04 through by I and substituting $I - I_R$ for I_G gives

$$I'/I = 1 - \frac{I_R}{I}(1-F) \qquad (5\text{-}05)$$

The ratio I_R/I in equation 5-05, called the roof fraction, is as important to dose reduction as is washdown effectiveness, F. This becomes evident when removal by the washdown is assumed to be 100 percent, i.e., F = 0. The remaining right-hand term, $I - I_R/I$, of equation 5-05 then

1. A third intensity, I_A, is also contributed by the radiation from fallout particles still suspended in the surrounding air. In a strict sense then, the roof and ground deposits comprise the total contribution only upon fallout cessation. However, the dose resulting from the air contribution is estimated to constitute but a small fraction of the total, long-term dose. For this reason, the intensities I_R and I_G are considered controlling.

represents the ultimate in dose reduction by washdown. This means that the roof fraction should be large, if washdown is to be worthwhile.

The variation of roof fraction,[1] for one-story buildings, according to several construction variables is shown in table 5-XVII[2] to more nearly approach unity as roof area increases, roof height decreases, and the ratio of roof to wall mass thickness decreases. Building designs exhibiting these characteristics stand to benefit most from the added protection of a washdown system.

By using table 5-XVII a rough approximation of the roof fraction can be made for a given set of construction variables. An estimate of washdown effectiveness can be made from table 5-XVI. Then equation 5-05 can be solved for the dose reduction factor. This indication of the protection gained through washdown will guide the designer's next course of action. Where the reduction factor is of the order of 0.1[3] or less, the washdown system may be found acceptable. Final judgement will depend upon some knowledge of the permissible dosage limits and the anticipated radiation fields.

Where the reduction factor is too large, indicating insufficient protection, removal effectiveness may be increased through improving the washdown system's components; e.g., a steeper roof pitch, a more wettable roof surface, and increased water flow rate. If these are not enough, washdown alone will not furnish the required protection and must be augmented or replaced by increased shielding.

Table 5-XVIII contains a number of solutions to equation 5-05 over a wide assortment of effectiveness/roof-fraction combinations. As expected, the significantly small reduction factors are associated with the higher roof fractions and the lower F values. Where the dose is to be reduced to less than 0.1 of its former amount, the entries in the lower right-hand quadrant of the table indicate that roof fractions must be 0.95 or more, and removal effectiveness must result in F values no greater than 0.05.

(b) Washdown and/or shielding. The discussion thus far does not mean to discount the value of increased shielding. No doubt there will be cases where washdown, for various reasons, will be impractical. For instance, washdown is limited to the reduction of potential

1. Roof fraction calculations are based on intensities at the building center only. As explained in section 5-01,b, corner intensities are strongly affected by ground contributions and are relatively insensitive to changes in building roof area.
2. Reference 31 in bibliography.
3. This is an arbitrary value which in most cases will correspond to the minimum gain in protection required.

Table 5-XVII. Roof Fraction for Single-Story Buildings as a Function of Roof Area, [illegible], and Roof Mass Thickness

		Roof Fraction (1_R, Z)								
	Height Above Floor:	[illegible] ft			[illegible]			[illegible] ft		
Roof Area (ft²)	Wall Mass Thickness (lb/ft²)	Roof Mass Thickness (lb/ft²) 12.5	37.5	75	Roof Mass Thickness (lb/ft²) 12.5	37.5	75	Roof Mass Thickness (lb/ft²) 12.5	37.5	75
1,000	12.5	.37			.21			[illegible]		
	25	.50			.31			.19		
	50	.69	.48		.50	[illegible]		[illegible]	.27	
	100	.89	.77	[illegible]	[illegible]	.63	[illegible]	[illegible]	.57	.38
	200	.99	[illegible]	[illegible]	[illegible]	.97	.93	[illegible]	.95	[illegible]
4,000	12.5	.51			.43			.29		
	25	.64			.56			.41		
	50	.80	.59		.74	.59		.62	.49	
	100	.93	.84	.60	.91	[illegible]	.58	.85	.70	.48
	200	1.00	[illegible]	[illegible]	[illegible]	[illegible]	.96	[illegible]	.98	[illegible]
10,000	12.5	.69			.56			.46		
	25	.73			.68			.59		
	50	.86	.63		.83	.57		.77	.60	
	100	.96	.87	.66	.95	.88	.64	.92	.85	[illegible]
	200	1.00	.99	[illegible]	1.00	.99	.97	.99	[illegible]	.97
40,000	12.5	.75			.71			[illegible]		
	25	.93			.81			.78		
	50	[illegible]	[illegible]		[illegible]	[illegible]		.94	[illegible]	
	100	.98	.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	200	1.00	[illegible]	[illegible]	[illegible]	1.00	[illegible]		[illegible]	[illegible]

Table 5-XVIII. Reduction of Dose (or Interior Radiation) as a Function of Roof Washdown Effectiveness for Various Roof Fractions.

Washdown Effectiveness, F (Fraction Remaining)	Dose (Rate) Reduction Factors, I'/I Roof Fraction, I_R/I							
	.20	.40	.60	.80	.90	.95	.98	1.00
.80	.96	.92	.88	.84	.82	.81	.81	.80
.60	.92	.84	.76	.68	.64	.62	.61	.60
.40	.88	.76	.74	.52	.46	.43	.41	.40
.20	.84	.68	.52	.36	.28	.24	.22	.20
.10	.82	.64	.46	.28	.19	.14	.12	.10
.05	.81	.62	.43	.24	.14	.10	.07	.05
.02	.80	.61	.41	.22	.12	.07	.04	.02
.01	.80	.60	.41	.21	.11	.06	.03	.01

roof intensities, while shielding can be used to protect against both roof and ground contributions. Some situations will be solved best by a combination of added shielding plus a washdown installation. When this appears to be the case, a more general expression than equation 5-05 must be used as a basis for decision.

The dose reduction factor due to washdown plus shielding is

$$I'/I = 1 - \frac{I_R}{I}(1 - FS) \qquad (5\text{-}06)$$

with S being the apparent effectiveness of increased roof shielding. Since the value of I_R assumes some initial roof shielding, S is in actuality the ratio of final to initial shielding affects.

$$S = S_a/S_b \qquad (5\text{-}07)$$

S_a and S_b are shielding factors and indicate the respective shielding effectiveness before and after increasing the roof thickness. Their values may be read off the curve in figure 5-17 for any roof mass thickness and substituted directly into equation 5-06.

The appearance of F and S as a product in equation 5-06 places greater importance upon the roof fraction (I_R/I) than if either F or S appeared singly. For example, if F and S are each assigned a modest (easily attainable) value of 0.1, their product will equal 0.01. The term in parentheses (1 - FS) becomes nearly unity, while the dose reduction factor approaches its optimum value of $1 - I_R/I$. Thus the roof fraction is more apt to become controlling when both washdown and shielding are used than when washdown is employed alone.

If it is decided that shielding alone is best, equation 5-06 can still be used by setting F equal to unity. Where a washdown system is considered best the value S is made unity. This of course gives the original expression for the dose reduction factor, equation 5-05.

(c) Comparative costs. Because buildings exhibiting a small ratio of roof to wall mass thickness tend to have large roof fractions, washdown should be well suited to the mixed construction discussed earlier in section 5-01,e. A typical example of such construction is a tilt-up concrete-slab building having walls 6 inches thick and a roof equivalent to 1 inch of concrete. For concrete these dimensions represent mass thicknesses of 75 and 12.5 pounds per square foot, respectively. Assuming a roof area of 10,000 square feet and a roof height of 20 feet, the roof fraction is 0.90 - by interpolation from table 5-XVII. A washdown effectiveness of 0.05 is not unreasonable for a moderately sloped, smooth, wettable roof system and a washdown flow rate of 2 to 3 grams per minute per square foot. Entering table 5-XVIII with these values, or using equation 5-05, the reduction factor becomes 0.14. To obtain the same protection through increased roof shielding alone would require an additional 6-1/2 inches of concrete.

Representative unit costs of washdown, besides other construction expenses, are:

Roof Area (ft^2)	1,000	4,000	10,000	40,000
Cost Units/ft^2	1.7	1.0	.75	.65

Increasing the roof shielding with 6 inches of concrete would require over 5 cost units per square foot regardless of the area involved. Compared to this alternative, the price of equivalent protection through washdown becomes more and more attractive with expanding roof area. In the above example of the 10,000 square feet tilt-up slab structure, adding 6 inches of concrete and installing a washdown system would provide a dose reduction

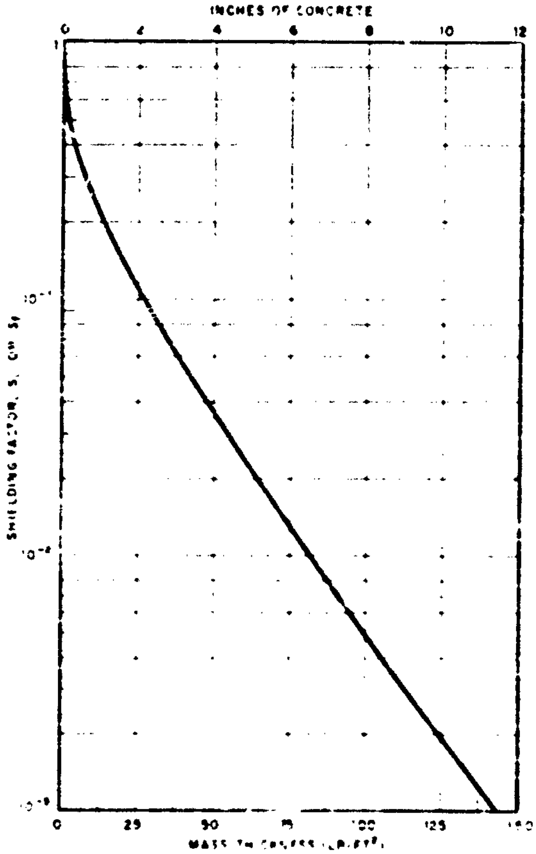

Figure 5-17. Roof Shielding Factors as a Function of Roof Mass Thickness.

factor of about 0.10. Equation 5-06 indicates this to be the largest reduction possible (for a roof fraction of 0.90) without increasing wall mass thickness.

b. Roof Blowdown System. Field tests[1] have demonstrated that air jets are very effective in removing simulated fallout from paved surfaces. Although no tests have extended this technique to roof surfaces it appears that an automatically operated, roof blowdown system using air is feasible. With the proper attention to aerodynamic orientation (see section 5-02,a), such a system could keep a roof relatively free of contamination during the fallout event much as would the washdown system.

The blowdown method offers significant advantages over a washdown. Since the decontaminating medium is ever-present, an air system is not complicated by the problems and expense of storage, recirculation or filtration. Assuming adequate air pressure, flat roofs could be protected just as well as those of positive slope.

The fact that a blowdown system does not collect the fallout particles may be objectionable but no more so than a once-through washdown system. In both cases the particles collect at ground level. If there is any wind, the particles resuspended during blowdown may actually be carried and deposited a safe distance away. Of course some neighboring structure may be contaminated. Hopefully, it will be so protected as to withstand this eventuality.

The most obvious drawback to a blowdown system is its ineffectiveness during wet weather. For this reason, its application is of greatest value in predominantly dry regions, where water is generally in short supply.

A blowdown system presents a number of engineering problems not encountered with washdown. Although both systems require headers, manifolds and nozzles, effective removal by blowdown can be accomplished only if the air jets can move across the roof. This is due to the fact that the air transport of particles stops just inches from the air nozzle. Fabricating and installing a traveling air jet manifold should cost no more than would washdown water storage, collection, and return systems.

Flexible hoses instead of pipes have to supply air to the moving manifold. A compressor has to furnish pressures in excess of 100 pounds per square inch. Its capacity will depend upon the dimensions of the roof and the number of air nozzles used and the removal rate desired. If the manifold is pneumatically powered, compressor performance must be increased. The compressor air inlet should be protected by a cascade baffle to prevent the entry of fallout particles into the system. As in the case of washdown an auxilliary power source must be included for the compressor. To obtain satisfactory design specifications and removal effectiveness information, considerable testing will have to be undertaken.

1. Reference 32 in bibliography.

c. Disposable Coverings. Probably one of the simplest ways of intercepting fallout is to cover the surfaces before its arrival. Upon cessation of fallout the covers are removed, leaving a clean surface behind. Such a technique is especially adaptable to small objects, but large surfaces also can be protected this way. Tarpaulins have been used for years to protect athletic grounds from rain or snow. In some instances the rolling and unrolling of these canvas covers have been achieved by mechanical means.

Thus where ground areas are reasonably flat the covering and final roll-up could be achieved remotely. A powered spool with contaminated cover could store itself in a trench serving as a shielded depository. Some modifications of this design possibly will work on certain roofs. However, removable covers, even though actuated mechanically, are no substitute for a roof washdown or blowdown system. Since the [illegible] must remain in place until fallout ceases to effect a complete d[illegible]mination, it cannot lessen the dosage accrued by building occupants during this period. Once the fallout event is complete, roll-up of protective covers offers an effective means for immediately reducing the dose accumulating indoors.

Figure 5-18 demonstrates two possible schemes for installing removable covers for buildings. On sloping roofs gravity will roll out the cover upon release of the spool. Freeing the fixed upper edge at the ridge after fallout ceases will allow the cover to roll down the slope and plummet to the ground, carrying the contaminant within it. For flat roofs a powered spool is required. It will have to be lowered to the ground on lines in the roll-up phase of the operation. Once on the ground, contaminated rolls will have to be shielded in trenches or behind revetments to protect occupants of thin-walled buildings. In any case, the cover system will have to be comprised of a number of independent minor covers capable of rolling between vents, chimneys, sky lights, etc.

5-05. VENTILATION OF SHELTER SPACES. The presence of fallout on and around buildings raises the possibility of entrance and contamination of interior spaces. Fortunately, this can be averted through complete, though not airtight, closure. That is, all windows and outer doors will prevent the entry of significant amounts of fallout.

Because it may be difficult to accurately detect the arrival and cessation of fallout, complete closure should be instituted at the first sign or warning of a nuclear attack and maintained well beyond the estimated time of fallout cessation. Thus, for non-air-conditioned structures, the supply of fresh air via normal routes will be denied to shelter occupants for a day or more. However, air leaks through most building walls and cracks around doors and windows to supply adequate ventilation even when they are closed.

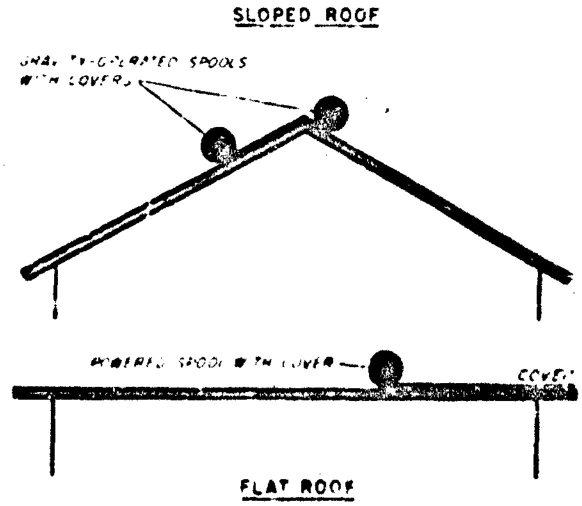

Figure 5-18. Schematic Diagram of Automatically Removable Covers for Buildings.

Under crowded situations or where personnel are working, the environment may eventually become uncomfortable, if not offensive. This condition can be tolerated for protracted periods depending upon the existing air volume and the number of people involved. The capabilities of persons so confined are seriously affected as the oxygen content of the air diminishes to about 14 percent or the CO_2 content exceeds 3 percent. Table 5-XIX indicates the minimum amount of make-up air required for sedentary workers for three environmental conditions.[1] Where it is believed that the secured condition will become unbearable, or where mission personnel must maintain a given level of performance, the existing air may have to be replenished by a forced ventilation system.

Deliberately pulling outside air into a building during a fallout event would at first appear to create an interior contamination problem. Fortunately, the filters used in modern air conditioning systems are usually capable of intercepting particles ranging down to the sub-micron sizes.

1. Reference 33 in bibliography.

Table 5-[illegible]. Air Supply Requirements for Sedentary Adults as a Function of Unit Air Volume and Ventilation Conditions.*

	Air Space/Person (ft^3)	Air Supply/Person (ft^3/min)
Heating season; with or without circulation; air not conditioned:		
	100	25
	200	15
	300	12
	500	7
Heating season; air humidified, water atomization rate 8 to 10 gph; total air circulated, 30 cfm per person:		
	200	4
Summer season; air cooled and dehumidified; total air circulated, 30 cfm per person:		
	200	4

*More complete coverage of air requirements are contained in Corps of Engineers' Manual, "Collective Protection Against CBR Warfare", EM 1110-345-461.

The particle size range generally considered to be radiologically significant is in excess of 50 microns. Therefore, most existing air distribution systems could be used in comparative safety - without fear of serious interior contamination.

Absolute protection may be achieved by employing particulate filters such as those used by the U. S. Chemical Corps. Table 5-XX gives the more important characteristics of four such filters together with their approximate cost.[1] Although the filter cartridge is composed of water-repellent paper, it can be damaged by the excessive collection of moisture. The air inlet system should, therefore, be arranged to reduce this possibility.

Certain filters can be penetrated and damaged by the impaction of larger particles. The entry of abrasive fallout particles in quantity could interfere with the performance of the equipment. For the sake of protecting the air conditioning system, it is advisable to remove particles larger than 50 microns at the air intakes. This can be accomplished by such devices as inertial separators, baffle chambers and cyclones.

1. Reference [illegible] in bibliography.

Table 5-XX. Particulate Filters for Radiological Protection of Ventilation Systems.

Chem. Corps. No.	Dimensions (in.) Height	Width	Depth	Weight (lb)	Approx. Resist. (in. H_2O)	Capacity (cfm)	Cost ($)
C18	24	24	5-7/8	18	1.00	600	125
C19	24	24	11	40	1.75	1200	150
C30	24	46-1/2	11	64	1.75	2500	200
C20	48	48	11	120	1.75	5000	340

Care should be taken to protect living spaces from rooms housing air conditioning equipment, for two reasons. First, toxic gases from auxiliary engines cannot be tolerated within the shelter area. Second, the accumulation of fallout in filters may create a relatively strong radiation field within an equipment room. For these reasons, such spaces must be both sealed and shielded.

From the foregoing it would seem preferable to house ventilation equipment and machinery in a small annex to the main structure. However, isolation of spaces within a building can be accomplished as long as they are located along an outside wall. Basements offer excellent possibilities where they are not more important to basic shelter requirements.

It should be understood that, in a fallout situation, ventilation of buildings will be required only under certain conditions. Generally, survival will not depend on the mechanical distribution of air. Where it is planned to install air conditioning to meet daily requirements, advantage may be taken during an emergency of whatever comforts the system has to offer.

Although beyond the scope of this handbook, a word of warning should be given concerning the entry of toxic gases created by mass fires. Large-scale fires (covering many acres) may be expected to produce extreme concentrations of carbon monoxide (CO). Table 5-XXI[1] shows the effects on young healthy individuals after breathing air containing CO. Older persons, because of their inactivity are affected less quickly.

The dangers of oxygen deficiency and excessive concentration of CO_2 have already been mentioned. These hazards will be increased by mass

1. Reference 34 in bibliography.

Table XXI. Effects of Carbon Monoxide on Young Healthy Individuals.

CO Content of Inhaled Air (%)	Effects
0.02	Possible mild frontal headache after 2 to 3 hours.
0.04	Frontal headache and nausea after 1 to 2 hours. Occipital (rear of Head) headache after 2-1/2 to 3-1/2 hours.
0.08	Headache, dizziness and nausea in 3/4 hour. Collapse and possible unconsciousness in 2 hours.
0.16	Headache, dizziness and nausea in 20 minutes. Collapse, unconsciousness and possible death in 2 hours.
0.32	Headache and dizziness in 5 to 10 minutes, unconsciousness and danger of death in 30 minutes.
0.64	Headach and dizziness in 1 to 2 minutes, unconsciousness and danger of death in 10 to 15 minutes.
1.28	Immediate effect. Unconsciousness and danger of death in 1 to 3 minutes.

fires. However they become important only after the danger of CO has been eliminated.

Finally the high temperature of intake air may create an unbearable environment. Indoor temperatures of 100°F probably cannot be tolerated for more than a day without harmful effects to sheltered persons.

SECTION VI. APPLICATION OF PROTECTIVE PRINCIPLES
TO EXISTING BUILDINGS

Many of the protective improvements suggested in Section V to be included in the design of planned construction can be instituted in existing buildings but at increased cost. Generally, alterations for providing greater shelter effectiveness will be more expensive than those for improving recoverability. In any case, a number of improvements can be applied in varying degrees to existing structures, depending on the protective requirements and the available funds.

The protective principles for existing structures are, for the most part, a reflection of those already presented for new construction. For this reason, many of the graphs, tables and related information in Section V are relevant here.

6-01. IMPROVEMENT OF SHELTER EFFECTIVENESS. It was shown in section 5-01 that shelter effectiveness is largely a function of building size, shape, and massiveness. Any changes in the first two factors involves increases in plan area or number of stories. In many instances these alternatives will be not only impossible physically but prohibitive costwise. For existing buildings, then, weight of construction becomes the controlling factor. It will be remembered from section 5-01,c that this structural feature exerted the greatest protective influence. Thus, the problem of improved shelter effectiveness is primarily one of increased shielding.

a. Thicker Components. The importance of heavier construction to shielding (or shelter) effectiveness is clearly illustrated in figures 5-2 and 5-3. The advantage of increased mass thickness in any single building component is approximated by the curve of figure 5-9. For example, doubling the mass thickness of a concrete wall from 50 to 100 pounds per square foot (4 to 8 inches) raises it's shielding value by a factor of almost 9.

Since the elements comprising a building cannot be replaced cheaply their shielding can be improved only by thickening them with layers of materials. For walls this is no great problem. They can be faced with stucco, poured concrete, courses of brick or tile. Hollow blocks can be pumped full of grout to form more solid walls. Temporary measures such as sand-bagging or heaping with earth are very effective, if the original walls are sufficiently braced.

The mass thickness of floors and roofs in some cases can be increased by adding concrete. Of course, these members will have to be shored up first to support the extra weight. Thus the cost of increasing the mass thickness is liable to exceed that of originally constructing an equivalent

shield. Layering with earth or even flooding with several inches of water will furnish shielding in an emergency. Obviously the latter method would require some advanced surface preparation to prevent excessive leakage to occupied spaces. Flooding is of no value on roofs, however, since the fallout, being heavier than water, will settle onto the roof surface. The water will be above the radiation source, offering no added shielding to spaces below the roof.

As in the case of planned construction, a reasonably detailed analysis should be made of the existing shielding in a given building, along the lines suggested in Appendix E of Reference 1, before alterations are carried out. This will insure a more effective final result for a minimum cost.

b. Complete Closures. One of the first requirements of an effective shield is that it have no voids which will leak excessive amounts of incident gamma radiation. Thus the inherent shielding value of buildings may be increased by blanking off or baffling windows, skylights, doors, and vents, etc. (see section 5-01,g). Most windows simply can be filled in like the surrounding wall. Some doorways can be walled over. Important entryways may be fitted with heavy doors and backed up with baffles of dense materials such as bricks. Vent intakes probably will require some modifications involving dense baffles that allow passage of air but not radiation.

If it is not desirable to permanently seal windows they can be covered over with thin panels of wood or metal. Shielding can then be provided by stacking bricks or dense supplies in front of these locations. Baffles for doorways may be fashioned from piles of stores in the same way.

Eliminating openings in this way also lessens the chances for the contamination of building interiors by fallout particles. As mentioned before, complete closure of a structure will introduce the need for air conditioning and more artificial lighting. This is not a serious drawback where shielding becomes a matter of survival.

In the event that there is no air conditioning and it is not practical to furnish a sealed structure with a fully equipped system, temporary relief can be provided with a portable ventilation system. By combining particulate collectors (and/or filters) with flexible (or metal) ducting and blowers, living conditions can be greatly improved during emergency periods. Table 6-I[1] gives the approximate performance and cost of several such arrangements using the highly protective Chemical Corps. filters shown in Table 6-I. When it is planned to employ electric blowers, there should be an emergency power supply.

1. Reference 33 in bibliography.

Table 5-I. Filter Units - Filter Plus Electric Motor or Gas-Engine-Driven Blower

Capacity (cfm)	Length (ft)	Weight (lb)	Resist. (in. H_2O)	Cost ($)
600	5	700	1.00	720
1200	7-1/2	1100	2.00	850
2500	8	1600	2.00	1410
5000	8	2700	2.00	2250

c. Shelter Spaces. In some instances the cost of making an entire structure more massive to achieve adequate shelter will be unwarranted. For example, the components of wood frame buildings offer very little shielding. Moderate alterations would give little gain in protection. The more extensive changes needed would be very costly. For these and similar cases, or where funds are simply limited, it is best to construct a shelter within a structure.

A room or set of rooms can be designated as a shelter. The walls, floors and ceilings surrounding them can be sealed and built-up in the same way as suggested in the preceeding remarks about complete closures and increased weight of construction. To minimize the amount of added shielding, number of extra floor supports, and cost of alterations, spaces should be located either in a basement or on the floor directly below the upper-most story. Of course, other areas may be used, but the cost will be somewhat greater - unless advantage can be taken of certain natural shielding represented by stair wells, special partitions, extra thick floors, etc. Good use can be made of stacked supplies and heavy office furniture such as safes to further increase shielding where needed.

Considerable work has been done by the Office of Civil Defense in connection with the construction of shelter spaces in buildings. The reader is, therefore, referred to this authoritative source for detailed designs and performance of shelters.

6-02. REDUCTION IN COLLECTION OF FALLOUT. For reasons already covered, the contamination of buildings from fallout can be decreased by providing a smooth uncomplicated exterior. This may be achieved progressively as funds allow.

a. Good Housekeeping. A first consideration for any building involves good maintenance. That is, keeping all surfaces in a sealed and weatherable condition will improve their fallout resistance. Cracks and joints should be caulked, paint finishes renewed, and dirt and industrial films removed. Paints and repellants comparable to those shown in tables 5-XI and 5-XII are suggested for reducing contaminability.

b. Smooth Exteriors. Many of the architectural frills found on buildings constitute collection points for fallout. The removal of ledges, grooves, cornices, parapets and unessential adornments is recommended. During the walling up of windows to increase shielding, sills and any related trim can be disposed of. Other unneeded decorative items will require special attention.

After these frills are stripped off it may be necessary to fill and smooth over any irregularities with grout, stucco or mastic preparations. In some cases surfaces may deserve renewing with siding or roofing material. Refer to table 5-X and the eight examples given for achieving smoother surfaces. Residing and reroofing are expensive operations, but they usually increase the value of the structure.

c. Simplified Geometry. Changing the aerodynamic properties of an existing building to enhance the continued flight of approaching fallout particles promises to be an expensive propostion. It is possible that, where additions are planned to increase floor space, the building shape may be made more streamlined. For instance, filling out L-, T-, C-, and H-shaped plans to be more nearly rectangular should decrease eddying of air currents and hopefully the deposition of fallout.

The same conclusion may be made about the building outline when viewed in elevation. That is, building roof lines should be less complicated. Split levels, saw tooth roofs, and large projections (such as ducting, blowers, and water towers) disturb the air flow over buildings and may promote the collection of fallout particles. Probably the simplest way to alter this sort of irregularity is to install a false roof. If it is given a prominent slope (1 in 6 or more) the transport of deposited fallout from the roof by the elements will also be encouraged.

d. Special Devices. Washdown systems (and blowdown system) can be adapted to existing structures where the roof surface system is appropriate. It will not always be necessary to install as elaborate a system as is described in section 5-04. In fact a fairly crude but effective arrangement can be fashioned from fire hoses and temporary piping. When funds permit, a permanent system may be justified. If the roof system is suitable, the cost will be approximately as given in Section 5-04,a,(2). If it is necessary first to replace the roof or construct a false one, the cost may rival that of increased shielding. In any case, the weight of the pipe and water in the distribution system will have to be calculated

and checked against the load limit of the roof. Additional bracing will be required under the manifold supports, in extreme instances.

6-03. FACILITATION OF RECOVERY. Many of the ideas presented in section 5-03 are applicable to existing installations. Roofs easily can be made more accessible through added fire escapes and ladders. Services can be improved by modernizing the plumbing including standpipes and hose-houses. Fire systems should be augmented where necessary with additional lines, hydrants and pumping facilities. The water supply can be enlarged or supplemented from irrigation ditches, rivers, ponds and swimming pools.

Improving drainage characteristics and the accessibility of ground areas may prove to be more difficult. The latter probably will require relocating service poles, fences, hydrants, sheds and other obstacles to rolling equipment used during recovery. The graphs in figures 5-13, 5-14, and 5-15 are useful guides for establishing necessary clearances.

a. Roof Drainage. Drainage from roofs automatically will be improved where smoother materials have been introduced and the configuration simplified. False roofs can be sloped to provide the maximum drainage, as can the gutter and leader systems. Parapeted roofs bring up a problem. Where it is not advisable to remove the parapet, scuppers must be provided because central drains should not be used during wet recovery of flat roofs. These drains may become clogged with fallout material and create an interior radiation hazard to mission personnel.

Because flat roofs with parapets usually are topped with loose gravel, scuppers should be not only large but plentiful. Many pounds of gravel, fallout and water must leave the roof through these scuppers in a relatively short time. In order for parapets not to overly impede roof recovery by firehosing, scuppers should be at least 12 inches long by 6 inches high and be spaced no farther than 10 feet apart. Drainage and recovery of tar and gravel roofs can be greatly improved by the advance removal of all loose gravel with fire streams or brooms.

b. Ground Drainage. The extensive use of paving materials will make recovery a far more efficient process in the long run. Establishing adequate grades, as is pointed out in section 5-03,c, will assist greatly in the eventual disposal of radioactive solids washed from target surfaces. Since the cuts and fills in a built-up region cannot always be made to create a well-drained complex, certain stopgap measures often must suffice. Attention should be concentrated on roads, areas nearest buildings, and the waste disposal system.

Wherever possible, the slopes of these surfaces and systems should be made great enough to encourage the transport of fallout solids in run-off water. Road crowns can be built up, ramps can be substituted for steps, and sidewalks can be given a greater tilt toward gutters. Where the grade

of streets and gutters is minimal, more curb inlets should be installed. Storm drains and sewers can be augmented by systems of temporary trenches and ditches to receive runoff. The deposited fallout material cannot be expected to be carried by water flow to distant disposal points in unlined systems. For this reason the material excavated from these trenches or ditches should be left along their edges for back filling after completion of recovery. This will provide shielding against the radioactive waste. For this shielding to be adequate, such systems should be excavated to a depth of at least 2 but preferably 3 feet.

SECTION VII. PERFORMANCE OF RADIOLOGICAL RECOVERY METHODS

Although the basic objective of this handbook concerns the preattack preparation of targets for increased protection from fallout, an account should be given of the active countermeasures employed during the recovery phase of the radiological defense scheme. Without some knowledge of the expected performance of available decontamination methods, a large segment of the foregoing chapters lose some significance.

A great deal of effort has been made to develop suitable decontamination procedures and to determine their effectiveness. Not until recently, however, would a meaningful treatment of data obtained permit the correlation of removal effectiveness (F values) with such parameters as: anticipated fallout particle sizes and mass levels, recovery effort, equipment capability, procedural application and surface roughness. Some of the latest test results, interpreted in this useful framework, are given in the sections that follow. It should be understood that these results by no means are final. Considerable experimentation remains until the contributions of all the variables introduced by the weapon, the environment, and the disturbance due to recovery can be accounted for, measured, and understood.

7-01. WET METHODS. Probably the first method used in the large-scale removal of radioactive substances was firehosing. Being universally available, firehosing no doubt will be used more than any other method. Simple to carry out, firehosing requires no special skills. Its success depends upon adequate water pressure, thorough surface coverage by firestream, proper drainage and a certain amount of common sense on the part of the nozzle operator and hosemen.

Experience has shown that best results are obtained with a 1-1/2-inch rubber-lined firehose fitted with a straight taper fire nozzle having a 5/8-inch orifice. Smaller nozzle and hose combinations do not furnish sufficient water volume to move large masses of material. Larger combinations (2-1/2- or 3-inch sizes) are too unwieldy and are dangerous in unexperienced hands.

The 1-1/2-inch hose with fire nozzle offers the proper balance of maneuverability and removal effectiveness required of recovery tools. Table 7-I[1] shows the expected performance of a three-man hose team when cleaning tar-and-gravel and composition-shingle roofs. The first column gives the radiation intensity, at one hour after a nuclear detonation, corresponding to the amount of deposited fallout material shown in the second column. The manpower requirements and speed of operation are

1. Reference 7 in bibliography.

Table 7-1. Firehosing Roofs

Standard Intensity (r/hr)	Mass Loading (g/ft^2)	Unit Effort ($\frac{\text{man-min}}{10^3\ ft^2}$)	Rate per Nozzle (ft^2/min)	Water Consumption (gal/ft^2)	Fraction Remaining, F
		*Tar and Gravel - Practically no slope			
300	10	20	150	.3	.6
		30	100	.45	.3
		40	75	.6	.2
		60	50	.9	.1
1000	30	20	150	.3	.2
		30	100	.45	.1
		40	75	.6	.08
		60	50	.9	.05
3000	100	20	150	.3	.06
		30	100	.45	.03
		40	75	.6	.02
		60	50	.9	.01
		**Composition Shingles - Slope of 1/2.5			
300	10	5	600	.06	.09
		10	300	.12	.06
		20	150	.3	.045
1000	30	5	600	.06	.09
		10	300	.12	.06
		20	150	.3	.04
3000	100	5	600	.06	.09
		10	300	.12	.05
		20	150	.3	.03

* Nozzle pressures 60 to 70 psi.

**Nozzle pressures 60 psi when hosing at roof level and 40 to 45 psi when lobbing fire streams from ground level.

indicated in the next two columns. Method effectiveness appears in the last column, as the decimal fraction F of original radiation intensity or initial fallout mass level remaining after recovery.

Tar-and-gravel roofing is seen to require more cleaning effort due to its traditionally flat pitch and the estimated pound of loose gravel that must also be removed for each square foot of roof surface. The results given for composition shingles can be achieved by either lobbing firestreams from ground level or hosing directly on roof top, but the slope must be approximately as shown. Greater effectiveness than that shown for composition shingles may be expected on smoother materials - other conditions being the same. Conversely, rougher materials will result in less effectiveness and, as in the case of tar and gravel, will demand more effort.

When an extensive paved area such as a street is firehosed, a two-nozzle set-up is used. Each nozzle is fed by one 50-foot length of 1-1/2-inch hose connected to a wye gate. This is supplied in turn by a series of 2-1/2-inch hoses from a booster pump and hydrant. A jeep or pickup is employed to tow the heavy 2-1/2-lines, freeing the nozzle men to direct the firestreams. Table 7-II[1] lists the performance characteristics of such

Table 7-II. Firehosing of Pavements

Standard Intensity (r/hr)	Mass Loading (g/ft^2)	Unit Effort $\left(\frac{\text{man min}}{10^4\ ft^2}\right)$	Rate per Nozzle (ft^2/min)	Water Consumption (gal/ft^2)	Fraction Remaining, F (Concrete or Asphalt)
300	10	15	2000	.05	.06
		25	1200	.08	.04
		50	600	.17	.02
		100	300	.33	.015
1000	30	15	2000	.05	.06
		25	1200	.08	.04
		50	600	.17	.02
		100	300	.33	.015
3000	100	15	2000	.05	[illegible]
		25	1200	.08	.035
		50	600	.17	.02
		100	300	.33	.01

1. Reference 7 in bibliography.

Table [illegible]-III. Motorized Flushing of Pavements*

Standard Intensity (r/hr)	Mass Loading (g/ft^2)	Unit Effort $\left(\frac{\text{equip. min.}}{10^4\ ft^2}\right)$	Average Rate (ft^2/min)	Forward Speed (mph)	Water Consumption (gal/ft^2)	Fraction Remaining, F	
						Concrete	Asphalt
300	10	1	10,000	15	.045	.05	.06
		2	5,000	7.5	.09	.025	.035
		5	2,000	3	.22	.01	.02
1000	30	1	10,000	15	.045	.05	.055
		2	5,000	7.5	.09	.025	.035
		5	2,000	3	.22	.01	.02
3000	100	1	10,000	15	.045	.045	.05
		2	5,000	7.5	.09	.025	.03
		5	2,000	3	.22	.01	.015

*A conventional street flusher using the two forward nozzles and one side nozzle under a pressure of 55 psi. One man can operate a flusher, but two are better on older models having manually controlled valves.

an arrangement. Pressures of 75 to 80 psi at the nozzles are satisfactory. Five men are needed in all, two on each nozzle and one driver, plus a possible pump tender.

By way of comparison Table 7-III[1] demonstrates the fallout removal capability of conventional street flushers. It is immediately apparent that flushing is much faster than hosing and requires considerably less manpower. Flushers also offer the advantage of partial shielding to the operators, and reduce the recovery dose to about one half of that accrued by firehosing teams working in the same area.

Unfortunately street flushers are not nearly so plentiful as firehosing equipment. Substitute flushers can be improvised from tank trucks fitted with 500 gpm defense pumps and simple nozzle manifolds. Limited tests have shown that an improvised flusher can be competitive in performance with the more conventional types.

7-02. DRY METHODS. In order to make use of available equipment, a number of experiments have been conducted with conventional street sweepers. Typical performance characteristics of two different type of machines are given in table 7-IV.

Table 7-IV. Sweeping Pavements

Method	Standard Intensity (r/hr)	Mass Loading (g/ft^2)	1st Pass		2nd Pass		3rd Pass	
			E*	F	E*	F	E*	F
Wayne 450	300	10	11	.09	17	.07	23	.07
	1000	30	9	.07	16	.05	20	.03
	3000	100	14	.03	22	.02	-	-
Tennant 100	300	10	20	.07	30	.02	40	.015
	1000	30	20	.03	30	.015	40	.011
	3000	100	20	.025	30	.012	40	.010
Air Broom	300	10	16	.03	24	.015	32	.008
	1000	30	16	.03	24	.01	32	.007
	3000	100	15	.03	24	.009	32	.006

*Effort expended in man-min/10^4 ft^2.

1. Reference 7 in bibliography.

The Wayne 450 is a standard motorized sweeper using a main broom to pick up the material and deposit it on a conveyor system, which transports the material to a hopper. The sweeping speed of the Wayne ranges from 2 miles per hour to 8 miles per hour. An average sweeping speed of 5 miles per hour was used in obtaining the results presented.

The Tennant 100 is a recently developed vacuumized sweeper. The broom system is enclosed in a vacuum-equipped housing. The material picked up by the broom and the dust trapped by the filters is collected in a hopper. Sweeping speeds range from 2 to 15 miles per hour. An average speed of 3 miles per hour was used to provide these performance values.

Sweeping mechanisms of this general type permit a close control of the removed contaminant since it is confined in the hopper. Disposal is quick and automatic and can be performed at the area selected for collection of spoil. The build-up of contaminant in the hopper does represent a gradually increasing source of radiation to the driver. Dosage to operators should be constantly checked to avoid unnecessary over-exposure. The driver's position could be given greater shielding without too much trouble or expense.

A candidate method has been tested which shows some promise. This is the so-called "air broom", which sweeps by means of air jets. The latest air broom tests were conducted with a set of nine nozzles spaced 8 inches apart on an air manifold. This assembly was mounted on a compressor truck and positioned near the paved surface where it could blow contaminant to one side and past the shoulders of the road. Air pressure was approximately 100 pounds per square inch and air velocities were in the supersonic range. Results of these tests are included in table 7-IV.[1]

The air broom does not collect the material it sweeps but blows it off in a great cloud of dust which settles down-wind. For this reason the air-broom is best suited for decontamination of roads. Airbroom operation, then, must be planned according to prevailing winds to avoid recontamination of important facilities.

Some limited investigations have been made into the feasibility of vacuum cleaning. Present industrial cleaners are effective devices, but the contaminant removal rates are prohibitively slow.

7-03. LAND RECLAMATION. Fields and other extensive land areas may be reclaimed by surface removal and burial techniques with standard earth-working equipment. Typical effort and effectiveness values obtained on relatively flat surfaces are given in table 7-V.[2] Fallout mass loading has little affect on these two variables, since the contaminant makes up but a small percentage of the total quantity of earth being handled. This is true for either removal or burial processes.

1. Reference 32 in bibliography.
2. Reference 35 in bibliography.

Table 7-V. Reclamation of Unpaved Land Areas

	Effort (man min/1000 ft^2)	Fraction Remaining, F
Motorized Scraping (one man)		
1st Cycle	5-8	0.0016 -0.036
2nd Cycle	4	0.0002 -0.007
Motorized Grading plus Motorized Scraping (two men)		
1st Cycle	10-17	0.015 -0.124
2nd Cycle	9-17	0.00024-0.0041
Plowing (4-share gang-plow - one man)		
continuous	2.5	0.2
one direction only	4.8	0.2
Earth Filling (3 scrapers - 3 men)		
6" of fill	10-20	0.15
12" of fill	20-40	0.02
18" of fill	40-80	0.002

Motorized scraping is the most effective and efficient surface removal method, because it cuts cleanly with a minimum of spill and carries away the spoil for disposal. Grading requires more effort and can only windrow the spoil, which then must be hauled out of the area with scrapers or loaded into dump trucks for disposal.

Filling with layers of earth is probably the most costly burial method from the standpoint of manpower and equipment needed. However, where the surface contains rocks, stumps and the like, earth filling is about the only method suitable.[1] For this reason surfaces should be conditioned to enhance cutting and loading by motorized scrapers. Because it does not insure complete burial, plowing is not generally as effective as the previously mentioned methods. It is fast and is recommended for less sensitive areas such as along the sides of access-ways.

1. A system of dikes that permits controlled flooding is an alternate possibility where water is plentiful.

Large equipment cannot always be used in smaller spaces next to buildings. Here recovery must rely on drag-type scrapers and hand-shoveling. The following procedures result in F values of about 0.1 to 0.15. However the individual efforts, E, differ considerably.

(1) Scraping with farm type wheel tractor (operator plus laborer with shovel)

$$E = 24 \text{ to } 44 \text{ man min}/10^4 \text{ ft}^2, \text{ depending upon operator skill.}$$

(2) Scraping with jeep towing manually operated bucket (driver plus two laborers)

$$E = 100 \text{ man min}/10^3 \text{ ft}^2$$

(3) Shoveling and hauling with wheel barrows (4 laborers)

For light soil with some sod, $E = 135$ man min/10^3 ft^2
For rocky soil plus shrubs, $E = 220$ man min/10^3 ft^2

Loading and hauling spoil to a disposal area is not included in these effort values. This part of the operation of course will call for loaders and dump trucks.

7-04. COLD WEATHER OPERATIONS. All of the foregoing recovery procedures have been tried only in temperate climates. Where winter weather is encountered new problems are introduced. Higher radiation intensities could result from the purging of fine radioactive particles from the upper air by precipitation. The presence of snow or ice further complicates the situation, since the fallout might be under, within, or on top of this deposit. If under or mixed within, large quantities of these materials must be moved with the fallout. In addition, snow and ice cause loss of mobility to men and to equipment other than that designed for snow removal.

If it is assumed that a recovery effort can be mounted (with special equipment) in temperatures of 0°F to 10°F, delays of over one week are not likely. Temperature studies[1] over a 40-year period show that only the northern-most mid-western states have six or more unoperable days during the winter. If, due to lack of snow-removal equipment, temperatures of 20°F are judged critical, approximately one third of the United States could suffer a week or more delay in initiating recovery. This situation would apply still more to the middle and northern portion of the country. At any rate, it is certain that winter weather conditions will hamper recovery operations.

1. Reference 75 in bibliography.

Table 7-VI[1] presents the predicted performances for several candidate cold-weather decontamination methods. It should be noted that their application is determined by the depth of snow and, in certain cases, temperature and soil conditions.

Table 7-VI. Predicted Performance of Cold Weather Recovery Measures.

Method	When Applicable	Average Rate	Fraction Remaining
Skip loading	Over 3 in. of snow	12 ton/hr	0.1
Motorized sweeping	Under 3 in. of snow	10^4 ft^2/hr, per 1 in. of snow depth	0.1
Snow plowing	Over 3 in. mixed with contam., or under 3 in. with contam. on top	53 ton/hr, Blade type, 625 ton/hr, Rotary type	0.15
Firehosing	Above 10°F	7500 ft^2/hr, ground level 2000 ft^2/hr, buildings	0.01 0.05
Thawing + Firehosing	Above 10°F	2000 ft^2/hr, buildings	0.05
Thawing + Scraping	Cohesive soil	9000 ft^2/hr	0.01

In order to locate needed services and to guide the movement of reclamation equipment through heavy snow cover, colored poles should mark street corners, drains, hydrants and hidden obstacles. Rocks and stumps should be removed from open ground areas to prevent damage to rotary snow plow blades. To further implement the use of snow plows, these ground areas should be compacted and unmovable objects should be clearly marked by poles prior to the arrival of snow.

1. Reference 37 in bibliography.

Special note concerning the shelter calculations of section 5-01.

The roof and ground contributions determining the fractional intensities given in section 5-01 were calculated according to a method developed by Shapiro of U. S. NRDL and contained in reference 40. Since the completion of this section a number of other methods have also been published. The one currently receiving the most recognition in this country is that of L. V. Spencer. The OCD Guide for Architects and Engineers (reference 41) and the OCD Engineers Manual (reference 42) are both based on Spencer's work.

BIBLIOGRAPHY

1. Effects of Nuclear Weapons, U. S. Atomic Energy Commission, June 1957.

2. Alpen, E. L., Radiological Hazard Evaluation - A Critical Review of Present Concepts and a New Approach Thereto, U. S. Naval Radiological Defense Laboratory, Technical Report, TR-186, Oct 22, 1957.

3. Miller, C. F., Gamma Decay of Fission Products From Slow Neutron Fission of U235, U. S. Naval Radiological Defense Laboratory, Technical Report, TR-187, July 11, 1957.

4. Capabilities of Atomic Weapons, OPNAV INSTRUCTION 03400.1B, Nov. 1957 (Classified, unclassified portions only).

5. Kaanda, C. F., Gamma Radiations From Contaminated Planes and Slabs, U. S. Naval Radiological Defense Laboratory Technical Memorandum, TM-27, Jan 1, 1955.

6. Dhein, E. H., Protection and Decontamination of Land Targets and Vehicles, Operation JANGLE, Project 6.2, Final Report, WT-400, June 1952 (Classified, unclassified portions only).

7. Owen, W. L., et. al., Performance Characteristics of Wet Decontamination Procedures, Operation STONEMAN II, Vol. II, U. S. Naval Radiological Defense Laboratory Technical Report, TR-335, July 21, 1960.

8. Sartor, J. D., et. al., Cost and Effectiveness of Decontamination Procedures for Land Targets, Operation STONEMAN I, U. S. Naval Radiological Defense Laboratory Technical Report, TR-196, Dec 1957.

9. Strope, W. E., et. al., Specifications and Costs of a Standard Series of Fallout Shelters, U. S. Naval Radiological Defense Laboratory Technical Report, TR-366, Oct 6, 1959.

10. Shelberg, W. E., and Martin, S. B., An Exploratory Study of Protection Against Nuclear Thermal Radiation With Smoking and Intumescent Paints. U. S. Naval Radiological Defense Laboratory Technical Report, TR-241, June 2, 1958.

11. Broido, A., and Trilling, C., Thermal Vulnerability of Military Installations, U. S. Naval Radiological Defense Laboratory Technical Report, TR-10, Aug 11, 1955.

12. Clark, W. C., Window and Glass Hazards Under Wartime Conditions and Recommended Protective Measures, U. S. Atomic Energy Commission, AECU-3037, 1954.

13. Cannon, E. W., Building Materials as Commonly Used in Existing Urban Buildings in the United States, Project Civil, Contract No. CD-SA-56-57, Institute of Engineering Research, University of California, Jan 8, 1958.

14. Davis, H. S., "Composition, Properties and Cost of High Density Concrete," In Conference on Shielding and High Energy Accelerators, TID-7545, New York, New York, April 11, 1957.

15. Evans, B. H., Natural Air Flow Around Buildings, Texas Engineering Experimental Station, Research Report No. 59, 1957.

16. Gevantman, L. H., et. al., Contaminability of Selected Materials: Liquid Hold-up as a Measure of Their Contaminability, U. S. Naval Radiological Defense Laboratory Technical Report, TR-11, June 7, 1954.

17. Owen, W. L., Status of Radiologically Protective Coatings for Land Target Surfaces, U. S. Naval Radiological Defense Laboratory Technical Report. TR-277, Nov 13, 1958.

18. Heiskell, R. H., and Crew, R. J., Protective Coatings for Concrete, U. S. Naval Radiological Defense Laboratory Technical Report, TR-148, May 16, 1957.

19. Crew, R. J., and Heiskell, R. H., A Removable Radiological Protective Coating (RRPC) for Ships, U. S. Naval Radiological Defense Laboratory Technical Report. TR-403, Feb 12, 1960.

20. Abbet, R. W., American Civil Engineering Practice, Volume II, 1957.

21. Federal Specification WW-C-621a, Coupling, Hose, Cotton (Rubber Lined) and Linen (Unlined), Sept 20, 1951.

22. R. St. J. Orr, et. al., Forester Fire Protection Notes No. 2, Feb 1944.

23. National Fire Protection Association, Fire Hose Coupling Screw Threads, Standards For, NFPA No. 194, File 10 Series. June 1956.

24. Federal Specification WW-C-646, Couplings, Hose, Water Suction, Feb 21, 1956.

25. Heiskell, R. H., et al., Transport of Particulate Matter on a Near Horizontal, Ideal Surface, U. S. Naval Radiological Defense Laboratory Technical Report, TR-360, Aug 21, 1959.

26. Heiskell, R. H., et. al., Relation of Slope to Transport of Particulate Matter by Water Film on an Ideal Surface, U. S. Naval Radiological Defense Laboratory Report in publication.

27. Abbet, R. W. American Civil Engineering Practice, Vol. 1, 1957.

28. Owen, W. L., Interim Design and Evaluation of a Contact Water Curtain Against Fallout, for Roofing Materials, U. S. Naval Radiological Defense Laboratory Technical Report, TR-125, Nov 29, 1956.

29. Kehrer, W. S. and Clark, D. E., Small Scale Roof Washdown Effectiveness Test and Developmental Tests to Date of Washdown System Components, U. S. Naval Radiological Defense Laboratory Report in preparation.

30. Kehrer, W. S., and Hawkins, M. B, Feasibility and Applicability of Roof Washdown Systems, U. S. Naval Radiological Defense Laboratory Technical Report, TR-232, May 7, 1958.

31. Salkin, S., The Effectiveness of Roof Washdown Systems in the Reduction of the Radiation Intensity in Buildings, U. S. Naval Radiological Defense Laboratory Report in preparation.

32. Lee, H., et. al., Performance Characteristics of Dry Decontamination Procedures, Operation STONEMAN II, Vol. III, U. S. Naval Radiological Defense Laboratory Technical Report, TR-336, June 6, 1959.

33. Smith, G. P., et. al., Protection of Structures From Chemical, Biological and Radiological (CBR) Contamination, U. S. Army Chemical Corps Report, ENCR No. 30, June 1959.

34. Broido, A., and McMasters, A. N., Effects of Mass Fires on Personnel in Shelters, Pacific Southwest Forest and Range Experiment Station, Berkeley, California, Forest Service, U. S. Dept. of Agriculture, Technical Paper 50, August 1960.

35. Lee, H., et. al., Performance Characteristics of Land Reclamation Procedures, Operation STONEMAN II, Vol. IV. U. S. Naval Radiological Defense Laboratory Technical Report, TR-337. Jan 12, 1959.

36. Trilling, C., Analysis of Potential Delay in Radiological Recovery Due to Cold Weather in the U. S., U. S. Naval Radiological Defense Laboratory Technical Report, TR-261, Sept 2, 1955.

37. Taylor, D., et. al., Development of Radiological Decontamination Methods and Equipment for Cold Weather Regions, Y-F011-05-202 Type C NCEL Interim Report, July 15, 1960.

38. Personnel Shelters and Protective Construction, NAVDOCKS P-81, Sept. 1961.

39. Martin, S., On Predicting the Susceptibility of ... to Ignition by the Thermal Radiation from Nuclear ..., Naval Radiological Defense Laboratory Technical Report ...

40. Radiological Recovery of Fixed Military Installations, ... (Interim Revision, April 1958)

41. Fallout Shelter Surveys: Guide for Architects and Engineers, ... Document NP-10-2, National Plan Appendix Series, May 1960.

42. OCD Engineering Manual, Design and Review of Structures for Protection from Fallout Gamma Radiation - in press.

43. An Engineer Looks at Fallout Shelter - A Manual for Architects and Engineers - EMO Manual No. 1, Privy Council Office, Ottawa, Canada.

44. A Computation Method for Gamma Radiation Intensity in the Presence of General Shielding and Source Configuration - ... Report ..., Dec. 1957.

45. Auxier, J. A. et. al., Experimental Evaluation of the ... Protection Afforded by Residential Structures Against ... Sources, Civil Effects Test Operation, CEX 58.1, U. S. Atomic Energy Commission, 1959.

46. Guidebook for the Planning of Integrated Atomic Defense ... Selected Military Buildings Types, Contract NBY-3186 - A Study Conducted at the Pennsylvania State University for U. S. Naval Civil Engineering Laboratory, 1961.